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JERROLD®

TECHNICAL HANDBOOK FOR CATV SYSTEMS

BY KEN SIMONS

THIRD EDITION

JERROLD ELECTRONICS CORPORATION

TECHNICAL HANDBOOK FOR CATV SYSTEMS

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JERROLD ELECTRONICS CORPORATION
HATBORO, PENNSYLVANIA, U.S.A.

TECHNICAL HANDBOOK FOR CATV SYSTEMS
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PREFACE

This book on many important facets of CATV systems is a compilation of numerous papers and articles previously published and of lectures given by the author.

Ken Simons has been with CATV right from its inception in the early fifties and the contents of this book reflect his deep devotion to and involvement in the problems with which this fast-growing industry is confronted daily. Not only is the CATV industry deeply indebted to him for his contributions to the state of the art and to the opening up of a whole new area of industrial, educational, and consumer electronics markets with the accompanying creation of many thousands of jobs, but the public at large has greatly benefited by being able to view television broadcasts in areas where previously without CATV systems they could not.

Philadelphia, April 1968

GIDEON RATH, *Editor*
Jerrold Electronics Corporation
Engineering Publications Department

CHAPTER I

DECIBELS AND dBmV

The Need for dB Expressions

As the television signal progresses through a CATV system from the antenna through miles of cable and dozens of amplifiers, it undergoes many changes in power level before it is finally delivered to the subscriber's receiver. The power is very low at the beginning of the system, coming out of the antenna with a power level in the neighborhood of 0.0000000001 watt and increasing to around 0.0001 watt at the outputs of the distribution amplifiers. The wide range of power levels and all those zeroes (especially when you start doing calculations) make this a pretty cumbersome method to work with. There's a much better one, however, which utilizes elements known as decibels (abbreviated "dB") and decibel-millivolts (or "dBmV"). Restating the unwieldy quantities we used above in this method's terms, the antenna power would be expressed simply as "−20 dBmV" and the amplifier outputs as "+40 dBmV." The whole range between the two would then be expressed by numbers between −20 and +40. There is nothing mysterious about dB's and dBmV's. They show how basic mathematics is applied to create a simpler way of analyzing systems.

Decibels Start with Logarithms

Most secretaries would feel right at home with logarithms, which are really just a shorthand method of writing large or small numbers. You learned in school that the number 100 can be written as 10 x 10 or 10^2. That doesn't save much time. But if you have to write the number 100,000,000, or 10 multiplied by itself eight times, it's quicker to write it as 10^8. Or if you are faced with 0.00000001 (which is 1/100,000,000 or $1/10^8$), it's just 10^{-8}.

All the numbers you put in this form, 10^2, 10^{-8} or even 10^{77} have one thing in common, the "base" number of 10. The idea of logarithms is to use this fact to carry our shorthand one step further. We don't bother writing the 10 at all. We just write the exponent—the power to which 10 is raised to get the number—and call it a logarithm or "log" for short. The logarithm for our old friend 100,000,000 or 10^8, is 8. To remind us that it is 10 that is raised to the power of the logarithm, the log is referred to as log to the base 10, abbreviated $\log_{10}$. So, logarithm to the base 10 of 100,000,000, written $\log_{10}$ 100,000,000, is 8. Remembering that 1/100 or 0.01 = 10^{-2} then $\log_{10}$ 0.01 = −2, and so on, as you can see from the following table A of examples.

TABLE A

Number	in terms of power of 10	Logarithm (to base 10)
10,000,000,000	10^{10}	10
1,000,000,000	10^9	9
100,000,000	10^8	8
10,000,000	10^7	7
and so on down to		
10	10	1
1	10^0	0
0.1	10^{-1}	−1
0.01	10^{-2}	−2
down to very small numbers like		
0.000,000,000,1	10^{-10}	−10

The Bel and the Decibel

When telephones were first put into use it was discovered that the longer the wires between two phones, the weaker the signal arriving at the receiving end became. The convenient and obvious method for expressing how much the signal has weakened was to do so in terms of a length of "standard" cable. Just as 110 volts means a quantity 110 times a standard of one volt, the telephone people would refer to a weakening of a signal as being some number of times that which would occur in a mile of this standard cable.

As time went by, the telephone people further discovered that 10 miles of the standard cable reduced the signal power by a factor of approximately 10 times. They set up this amount of attenuation (decrease), namely 10 to 1 power loss, as a unit. They called it a "bel," inspired by the name of their company's famous founder. Mathematically, they defined the bel in logarithmic terms since it described signal attenuation in logarithmic rather than simply linear terms. The formula is:

$$\text{Loss (in bels)} = \log_{10} \frac{\text{input power}}{\text{output power}}$$

When input power = 10x output power, this becomes a loss (in bels) = $\log_{10}$ 10 = 1; in other words, a loss of 1 bel corresponds to a reduction of 10:1 in power.

Just as a farad was discovered to be too large for practical use, so that most capacitors are measured in microfarads or picofarads, the bel was found to be too clumsy. The unit which came into use was the one-tenth-of-a-bel or "decibel" (abbreviated "dB"). Adjusting our formula to read in decibels, we find that:

$$\text{Loss in decibels} = 10 \log_{10} \frac{\text{input power}}{\text{output power}}$$

A decibel then was the attenuation caused by a mile of the standard phone cable. The important feature to remember about a dB is that it is an expression of a ratio between two levels — an input and an output. We've originally stated this as a ratio between two power levels, but it can be used for voltage or current levels as well. Assuming the input and output impedances are the same, we can convert the formula directly:

$$\text{Since Power} = \frac{E^2}{R},$$

$$\frac{\text{input power}}{\text{output power}} = \frac{(\text{input voltage})^2}{(\text{output voltage})^2}$$

We know that:

$\log_{10}$ (any number)$^2 = 2 \log_{10}$ (that number).

For example, $\log_{10} (27)^2 = 2 \log_{10} 27$.
so

$$\log_{10} \frac{(\text{input voltage})^2}{(\text{output voltage})^2} = 2 \log_{10} \frac{\text{input voltage}}{\text{output voltage}};$$

and since loss in dB =

$$10 \log_{10} \frac{\text{input power}}{\text{output power}} = 10 \log_{10} \frac{(\text{input voltage})^2}{(\text{output voltage})^2},$$

then Loss in dB =

$$10 \left(2 \log_{10} \frac{\text{input voltage}}{\text{output voltage}}\right) = 20 \log_{10} \frac{\text{input voltage}}{\text{output voltage}}$$

and similarly for current ratios.

How this works out for a range of voltage and power ratios can be seen in table B:

(The two voltages must be measured at the same impedance level.)

TABLE B

Input power / Output power	Loss in dB	Input voltage / Output voltage
10,000,000,000	100	100,000
100,000,000	80	10,000
1,000,000	60	1,000
10,000	40	100
100	20	10
1	0	1

The dB can also be used to express gain, the opposite of loss. The formula becomes:

$$\text{Gain (in dB)} = 10 \log_{10} \frac{\text{output power}}{\text{input power}},$$

or, for voltage:

$$\text{Gain (in dB)} = 20 \log_{10} \frac{\text{output voltage}}{\text{input voltage}},$$

and again, similarly for current.

The dBmV

Power levels at various points in a CATV system are of primary importance, forming the technical basis of system operation. The antenna output must be high enough to provide noise-free pictures. The amplifier output must be held to optimum level for minimum system noise and cross-mod. To express **levels** (as contrasted with power **ratios**), a standard reference level is needed so the dB ratio of the power at any point in the system to this standard level can be computed. Early in the history of CATV systems the power corresponding to an RMS* voltage of 1 millivolt across 75 ohms was chosen as the reference. This is approximately the input required for a noise-free picture on an ordinary receiver, so its use provides dB levels indicating approximately how much attenuation is allowable between the point in question and the receiver.

The level at any point in the system expressed in dB's above the 1 millivolt/75-ohm standard is said to be the level in decibel-millivolts or dBmV. In other words: voltage level (in dBmV) =

$$20 \log_{10} \frac{\text{voltage in millivolts at that point}}{\text{standard level (1 millivolt)}}$$

when the voltage is measured at the 75-ohm impedance level.

Simplified, this reads:

dBmV = 20 $\log_{10}$ (voltage in millivolts) at 75 ohms impedance;

Table C shows the dBmV levels in a 75-ohm system corresponding to decade multiples of 1 microvolt.

TABLE C

RMS voltage across 75 ohms	dBmV
1 volt	+60
100 millivolts	+40
10 "	+20
1 "	0
100 microvolts	−20
10 "	−40
1 "	−60

* RMS = root mean square; explained on page 4.

Tables D and E can be used to find the voltage for any integral number of dBmV. Follow the applicable rule:

For Positive dBmV:

1. Subtract from the given level that multiple of 20 dB giving a level within the range of Table D.
2. Multiply the voltage found opposite that level by the multiple of ten corresponding to the dBs subtracted:

If you subtract	Multiply millivolts from Table D by
20 dB	10
40 dB	100
60 dB	1,000
80 dB	10,000

For example: Given + 78 dBmV.

1. Subtract 60 dB giving +18 dBmV. Corresponding voltage is 7.94 millivolts.
2. Multiply by 1,000 (corresponding to the 60 dB added). Voltage corresponding to +78 dBmV is 7.94 × 1,000 = 7,940 millivolts or 7.94 volts.

TABLE D

For + dBmV			
dBmV	Millivolts	dBmV	Millivolts
0	1.00	+10	3.16
+1	1.12	+11	3.55
+2	1.26	+12	3.98
+3	1.41	+13	4.47
+4	1.59	+14	5.01
+5	1.78	+15	5.62
+6	2.00	+16	6.31
+7	2.24	+17	7.08
+8	2.51	+18	7.94
+9	2.82	+19	8.91
+10	3.16	+20	10.00

For Negative dBmV:

1. Add to the given level that multiple of 20 dB giving a level within the range of Table E.
2. Divide the voltage found opposite that level by the multiple of ten corresponding to the dBs added:

If you add	Divide microvolts from Table E by
20 dB	10
40 dB	100

For example: Given −59 dBmV.

1. Add 40 dB, giving −19 dBmV. Corresponding voltage is 112 microvolts.
2. Divide by 100 (corresponding to the 40 dB added) giving 1.12 microvolts.

TABLE E

For − dBmV			
dBmV	Microvolts	dBmV	Microvolts
0	1000	−10	316
−1	891	−11	282
−2	794	−12	251
−3	708	−13	224
−4	631	−14	200
−5	562	−15	178
−6	501	−16	159
−7	447	−17	141
−8	398	−18	126
−9	355	−19	112
−10	316	−20	100

Conversion Tables

Chapter XI contains Tables V3, V4, V5 and V6 which allow more accurate conversion between dBmV and voltages than the example Table E above. In addition, other tables and charts are given for converting between decibel expressions and related electrical quantities. How those tables were derived and how to use them is explained in the following chapters.

Signal Voltage in CATV Systems

We know that when we speak of a picture level of, say, +20 dBmV, we mean that the voltage is 20 dB above one-millivolt-across-75-ohms, or 10 millivolts. But what exactly do we mean by that?

An actual picture signal is a high frequency sinusoidal carrier modulated with video information. Its peak amplitude varies all the time. Does our 10 millivolts refer to average voltage, peak voltage, effective voltage or what?

A quick review of some fundamentals may help to understand. Consider the relationships in a simple dc circuit as shown in Fig. 1:

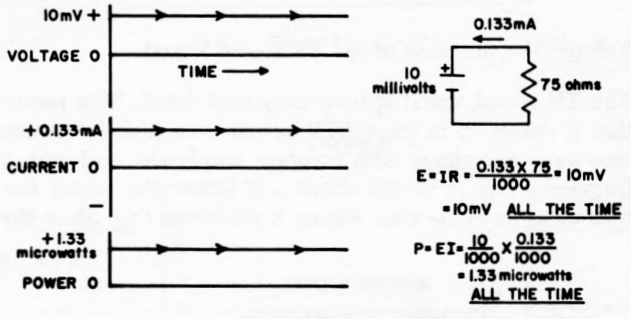


Figure 1.

In a dc circuit like this everything is easy, because all the quantities are constant. The voltage is 10 millivolts **(all the time)**, the current is 0.133 mA **(all the time)** and the power is constant. There is no difficulty agreeing on what each quantity means in this situation.

When the voltage and current vary with time there is need for explanation. What kind of voltage is meant? Consider a circuit, similar to that in Fig. 1, but with sine-wave ac voltage and current as shown in Figure 2.

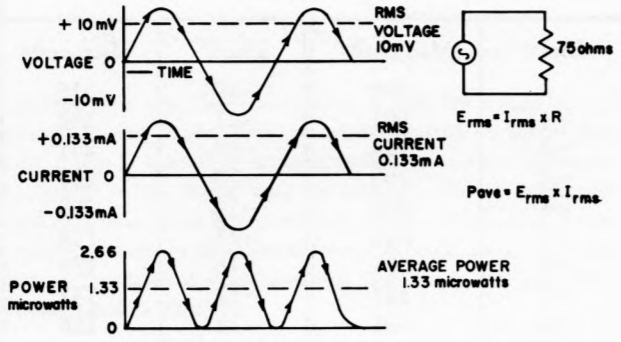


Figure 2.

Since the voltage, current and power are varying all the time, they can be expressed or measured by a single number only after there is agreement as to what that number means in reference to the varying quantities. In the case of sine-wave ac, "RMS" voltage and current are generally used. The RMS quantities are the effective quantities. An **ac** voltage of 10 millivolts RMS will have the same "effect," that is, it will cause the same average power loss in a resistor, as a 10 mV **dc** voltage. Although the actual voltage in the above circuit reaches plus and minus peaks of 14.14 millivolts, 10 millivolts describes its "effect." The current goes to plus and minus 0.188 mA, but its heating effect is the same as that of a dc current of 0.133 mA. The power reaches 2.66 microwatts but the **average** power is 1.33 microwatts. Using RMS quantities simplifies calculations by making the product of RMS volts times RMS amps. equal to average watts.

Note that, for a constant amplitude sine-wave voltage or current, the RMS value is always 0.707 x the peak voltage or current.

Voltage Measurement of the TV Sound Signal

The TV sound signal is frequency-modulated. This means that it shows up in the CATV system as a high-frequency sine-wave ac voltage with constant amplitude, and with a frequency that is varied above and below the center frequency at an audio rate. Figure 3 illustrates this. Since the amplitude is constant, the sound signal is measured in terms of the RMS voltage present, just like a c-w signal, its effective voltage being 0.707 x the peak voltage.

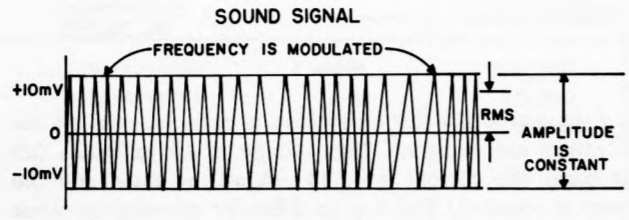


Figure 3.

Voltage Measurement of the TV Picture Signal

The TV picture signal in a CATV system is amplitude-modulated. It shows up as a high-frequency sine-wave ac voltage with constant frequency, but with amplitude varied by the picture information. At the end of each horizontal line it goes to full amplitude during the sync pulse, as shown in Figure 4.

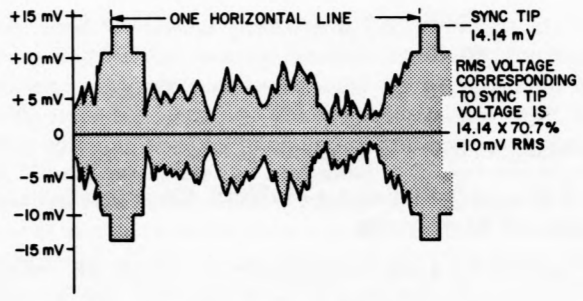


Figure 4.

When the picture is viewed like this, with the oscilloscope timed to show one horizontal line, the individual cycles of sine-wave variation are not seen because there are so many of them. During one horizontal sync pulse the voltage of a Channel 6 TV signal, for example, goes through more than 400 cycles. As the camera scans, the part of the signal between sync pulses constantly changes in amplitude to spell out the picture information. The only part of the signal that does not change in amplitude is the pedestal and the sync pulse. For this reason, signal strength measurements for a modulated TV picture signal are always referred to the sync level. The statement "the pix level is +20 dBmV" or "There is 10 millivolts of picture signal" means that the amplitude of the ac voltage **during the sync pulse** is the same as the amplitude of an unmodulated 10-millivolt RMS signal. Another way of saying the same thing is: "a modulated TV picture signal is measured in terms of 0.707 times its instantaneous peak value" (which peak occurs at the maximum of each cycle during the sync pulse).

Field Strength Meter Calibration

Field Strength Meters for CATV are generally calibrated so they read the RMS voltage and the dBmV level of the signal to which they are tuned. In the calibration procedure of Jerrold Models 704-B and 727 the instruments are adjusted to read correctly on an accurately measured c-w signal. Since the detector which drives the indicating meter responds only approximately to the peak of the signal (even though the meter indicates RMS) the indication is slightly low when a TV picture carrier is tuned in. This error is usually quite small, in the order of 1 dB or less, depending on how close the detector comes to responding to true peak voltage.

CHAPTER II

THE COMBINATION OF VOLTAGE, CURRENT, OR POWER

Introduction

To analyze the operation of a CATV system it is essential to understand how electrical quantities combine to produce a final result. The way in which noise and distortion combine in a cascaded amplifier system to produce a net effect at the output of the last amplifier determines the requirements on each amplifier. How the signal "splits" or "divides" in a customer tap or line splitter determines the net effect on system levels.

This understanding is approached by first considering a few simple cases involving the addition of voltage, current or power.

Voltage and Current Addition—DC

First consider the conditions that exist in the simple dc circuit shown in Fig. 5. A constant voltage* dc source maintains a 1-volt drop across a 100-ohm resistive load. The load draws a current of 10 mA and dissipates 10 mW, which is the power output of the source.

Similarly Fig. 6 illustrates a constant-current** dc source. This source maintains a current of 10 mA through a 100-ohm load. The voltage drop is 1 volt, and the load dissipates the full output of the source, which also is 10 mW.

Now consider what happens when a second equal voltage source is connected in series with the first (compare Fig. 7 with Fig. 5). It is not surprising to find that, with twice the voltage, the 100-ohm load draws twice the current, 20 mA. It is perhaps a little surprising, when you think about it, that the power dissipated in the load, which is the same as the power output of the two generators, is 40 mW, 4 times what it was with only one source. The presence of the second source increases the current flow through the first, so the power output of the first is doubled.

When a third source is connected in series, as indicated in Figure 8, the voltages add to produce 3 volts across the load, resulting in a current of 30 mA and in a power of 90 mW. In summary, as sources having equal voltages are added in series, the power output into a common load in-

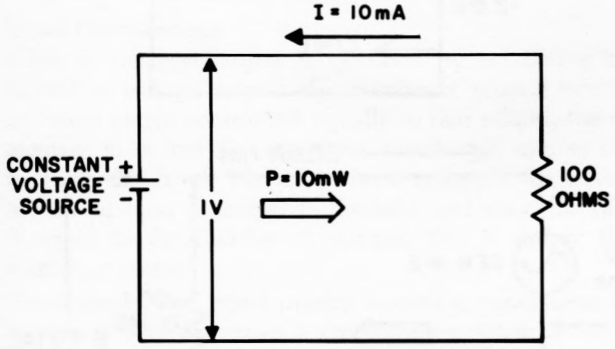


Figure 5.

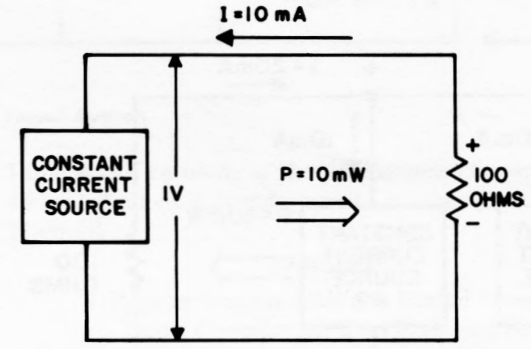


Figure 6.

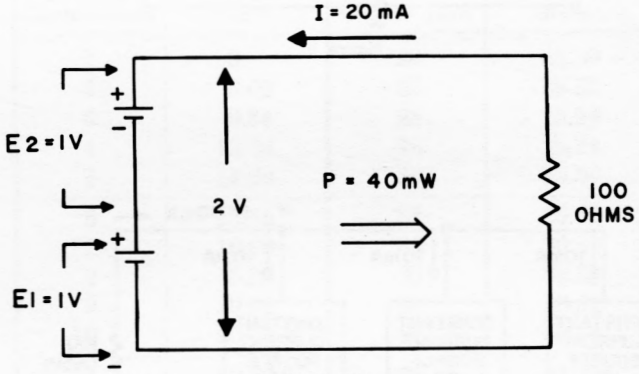


Figure 7.

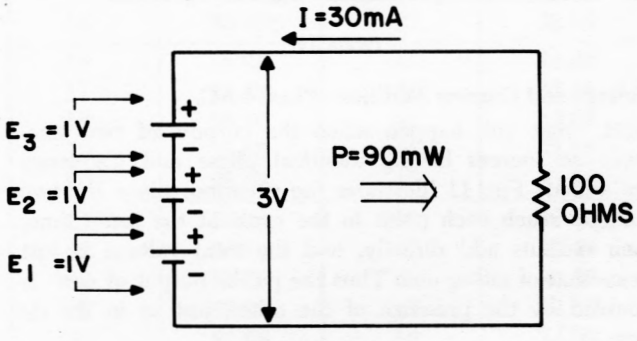


Figure 8.

* A constant-voltage source maintains the same output *voltage* regardless of load. The internal resistance of a constant-voltage source is very *low* compared to the load resistance.

** A constant-current source maintains the same output *current* regardless of load. The internal resistance of a constant-current source is very *high* compared to the load resistance.

creases as the square of the total voltage ($P = \frac{E^2}{R}$).

The situation is similar when two currents are added. When a second current source is added, causing a second 10-mA current to flow in the 100-ohm load (compare Fig. 9 with Fig. 6), the total current of 20 mA causes a voltage drop of 2 volts, and a dissipation in the load of 40 mW. The presence of the second source increases the power output of the first.

Similarly, when the outputs of three constant current dc sources are combined to feed a common load as illustrated in Fig. 10, the current through the load is three times the current from one source and the power dissipated is nine times the power that would be dissipated with a single source and the same load. ($P = I^2R$).

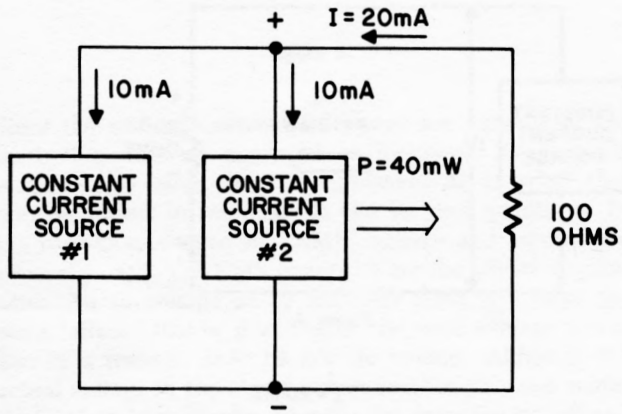


Figure 9.

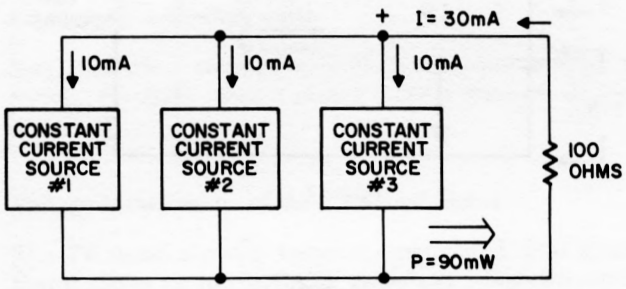


Figure 10.

Voltage and Current Addition—Phased AC

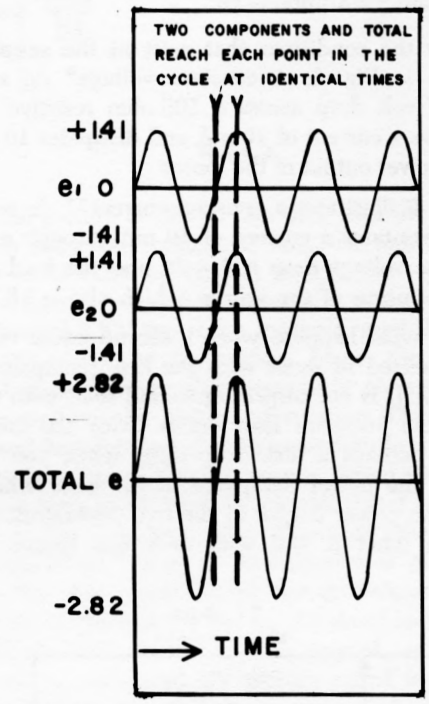
Next, what will happen when the outputs of two sinewave ac sources having identical phase and frequency are added? Fig. 11 illustrates the situation: Since the two voltages reach each point in the cycle at the same time, their outputs add directly, and the total voltage is just twice that of either one. Thus the power output of each is doubled by the presence of the other, just as in the dc case.

When ac voltage or current components have identical frequency and phase, as in Fig. 11, they are said to be phased. A general rule can be formulated for the addition of phased voltage or current components:

When the ac voltages (or currents) from a number of phased sources are combined, the total rms voltage (or current) is the sum of the individual rms voltages (or currents).

Example: The output currents of six phased ac sources are combined in a 1000-ohm load as shown in Fig. 12. What is the total current, what power is dissipated in the load, and how many dB is this power increased over that dissipated by source #1 only?

Solution: Since the sources are phased, the total rms current is simply the sum of the given currents: 1 + 4 + 11 + 3 + 6 + 5 = 30 mA. The power dissipation is I^2R = 30/1000 × 30/1000 × 1000 = 0.900 watts. The power dissipation with source #1 alone would be 1 mA through 1000 ohms, or 1/1000 × 1/1000 × 1000 = 0.001 W.



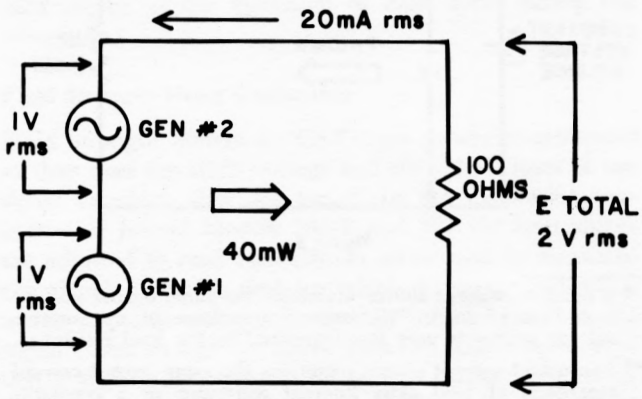


Figure 11. Two Sinewave AC Sources, Same Frequency, Same Phase.

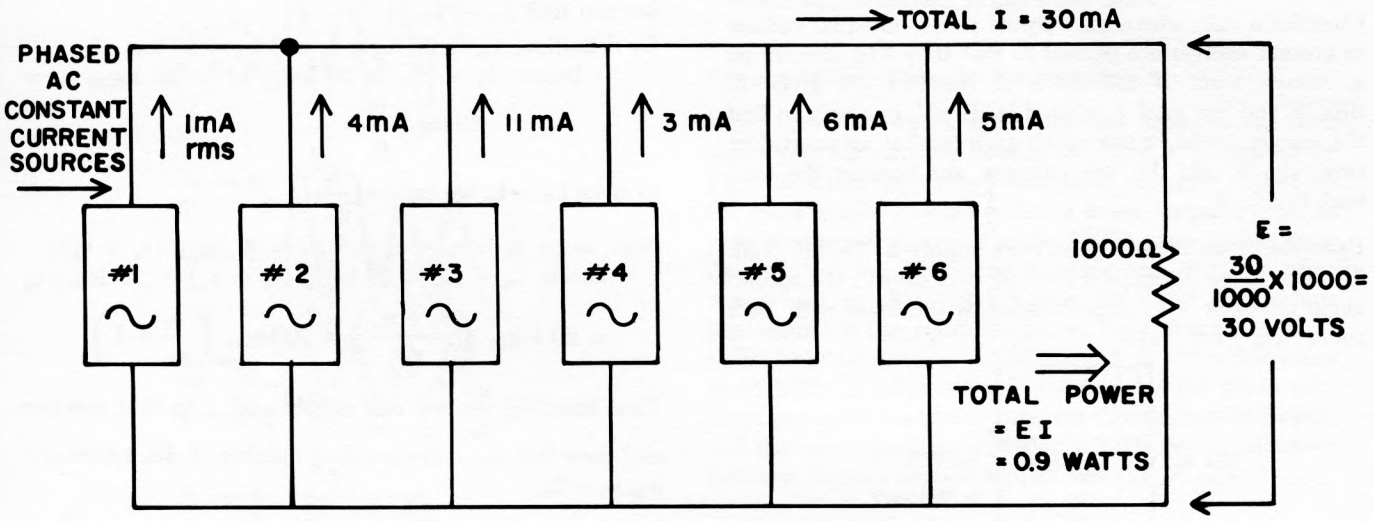


Figure 12. Addition of Phased Currents.

The power ratio is 0.900 divided by 0.001 or 900. From Table P7 in Chapter XI we find that the dB number for a power ratio of 9 would be 9.54 dB; adding 20 dB corresponding to a power ratio of 100, the solution is 29.54 dB.

One step in the calculation of the dB expression could be eliminated by simply using the current ratio. The total current is 30 mA, an increase of 30 times over 1 mA from source #1. From Table V6 we get that a current ratio of 30 corresponds to 29.54 dB.

General rule for finding the dB increase for a combination of phased sources:

To find the dB increase when the outputs of phased voltage or current sources are combined, add the voltages (or currents) and use the voltage-dB table to find dB corresponding to the ratio of the total to the original voltage or current. This kind of combination is called "Voltage (or current) addition."

Equal Contributions

When a common output is obtained by combining the current or voltage outputs of a number of phased sources, and each source contributes equally to that output, the dB increase in output for any given number of sources can be easily tabulated. The dB increase is simply the voltage or current ratio expressed in decibels, and since the ratio is equal to the number of sources, this is simply that number expressed in dB.

For example; two equal phased sources in series generate an output 6.02 dB above a single source, since $20 \log_{10} 2 = 6.02$.

Table F has been prepared to show these dB ratios for numbers of equal contributions from 1 to 50 sources.

Example: By how much will the output of a system increase when 45 equal, phased sources in series are used as compared with the output of one such source?

Solution: Since voltage addition is applicable in this case, Table F can be used; so the dB increase corresponding to 45 contributions is found opposite number 45 in the table, 33.06 dB.

TABLE F

Voltage or Current Addition, Phased Sources, Equal Contribution from Each Source

Number of Equal Contributions	dB Corresponding to This Ratio	Number of Equal Contributions	dB Corresponding to This Ratio
1	0	26	28.30
2	6.02	27	28.62
3	9.54	28	28.94
4	12.04	29	29.24
5	14.00	30	29.54
6	15.56	31	29.82
7	16.90	32	30.10
8	18.06	33	30.36
9	19.09	34	30.62
10	20.00	35	30.88
11	20.82	36	31.12
12	21.58	37	31.36
13	22.28	38	31.60
14	22.86	39	31.82
15	23.52	40	32.04
16	24.08	41	32.26
17	24.60	42	32.46
18	25.10	43	32.66
19	25.58	44	32.86
20	26.02	45	33.06
21	26.44	46	33.26
22	26.84	47	33.44
23	27.24	48	33.62
24	27.60	49	33.80
25	27.96	50	34.00

Voltage Addition—Two Unequal Contributions

Consider a case where the outputs of two unequal voltage or current sources are phased so that they add directly on a voltage basis. If the levels of the two are given in dBmV, and the total is wanted in dBmV, one way to find the answer would be to convert each level to an equivalent rms voltage, add the two voltages, and convert the total back to dBmV.

Example: Two phased generators supply a 75-ohm load. The first alone develops a level of +35 dBmV, the second alone develops +43 dBmV. What is the level with both connected? (Fig. 13).

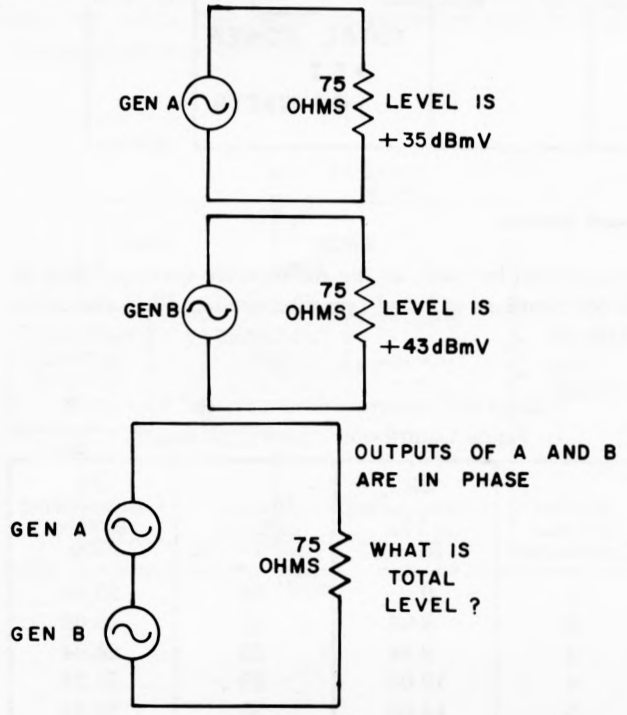


Figure 13.

Solution: From the dBmV-voltage table V7 find the rms voltages corresponding to the two levels: +35 dBmV corresponds to 56.23 mV; +43 dBmV corresponds to 141.3 mV. The total voltage is 56.23 + 141.3 = 197.53 mV. In Table V6 we find the corresponding level is about +45.9 dBmV.

This calculation can be simplified by the use of a table which allows making the calculation in dB language without converting to voltage. The table relates the difference in dB between the higher level and the lower to the difference between the total and the higher. The preparation of the table can be understood from the following:

Let:
L_s represent the lower level in dBmV, e_s the corresponding voltage in millivolts.
L_h represent the higher level in dBmV, e_h the corresponding voltage in millivolts.
L_t represent the total level in dBmV, e_t the corresponding voltage in millivolts.

We want a table arranged so that, when given $L_h - L_s$, we can find $L_t - L_h$.

By definition: $L_h = 20 \log_{10} e_h$ and $L_s = 20 \log_{10} e_s$;

hence: $L_h - L_s = 20 \log_{10} e_h - 20 \log_{10} e_s = -20 \log_{10} \frac{e_s}{e_h}$

so given $L_h - L_s$ we can find $\frac{e_s}{e_h}$;

Now, since: $e_t = e_s + e_h$ and $L_t = 20 \log_{10} (e_s + e_h)$;

hence: $L_t - L_h = 20 \log_{10} (e_s + e_h) - 20 \log_{10} e_h$

$$= 20 \log_{10} \left(\frac{e_s + e_h}{e_h} \right) = 20 \log_{10} \left(\frac{e_s}{e_h} + 1 \right).$$

Thus knowing $\frac{e_s}{e_h}$, we can simply add 1 to that number and then find the corresponding number of dB, representing $L_t - L_h$.

Example: let $L_h - L_s$ be 8 dB, then $\frac{e_s}{e_h} = 0.398$ and $\frac{e_s}{e_h} + 1 = 1.398$; then $L_t - L_h = 20 \log_{10} 1.398 = 2.91$ dB.

With this result the solution for the example in Fig. 13 is greatly simplified. Given two sources, having levels of +35 and +43 dBmV, and assuming voltage addition, the difference in level between the higher and the lower level is 43-35 = 8 dB. The level of the total is found by adding 2.91 dB ($L_t - L_h$ from above) to the higher level. 43 + 2.91 = 45.91 dBmV.

A table has been worked out showing $L_t - L_h$ for values of $L_h - L_s$ between 0 and 40 dB in 0.1 dB steps. This table is given as TABLE V8 in chapter XI; an example will illustrate its use.

Example: A source delivers an output into a 75-ohm load at a level of −12 dBmV. A second source, phased with the first and connected to an equal load, supplies an output at a level of −18 dBmV. What will be the level when both sources are connected to the same load?

Solution: In this case, voltage addition applies, thus Table V8 can be used. The difference in the levels of the two sources is 6 dB. Opposite 6 dB in the table we find 3.53 dB, the increase in the total level as compared with the level of the higher one of the two sources. The higher level is −12 dBmV (it is the smaller number, because both levels are negative). The resulting output level is found by adding 3.53 algebraically −12 + 3.53 = − *8.47 dBmV*.

Voltage Addition—Effect of Phase Variation

When two voltage sources have the same frequency, but different phase, their outputs reach various points in the cycle at different times so they do not add directly, and the rms voltage of the total is not equal to the sum of the two rms voltages. This is illustrated in Fig. 14 which shows each of two equal voltages and the total, for various phase relations between the two. When the phase angle is 0, the total voltage is twice either one. For small phase angles the total is only slightly reduced. When the second voltage lags the first by 90° the total voltage is 3 dB higher than either one (i.e. it is reduced 3 dB from the in-phase case)

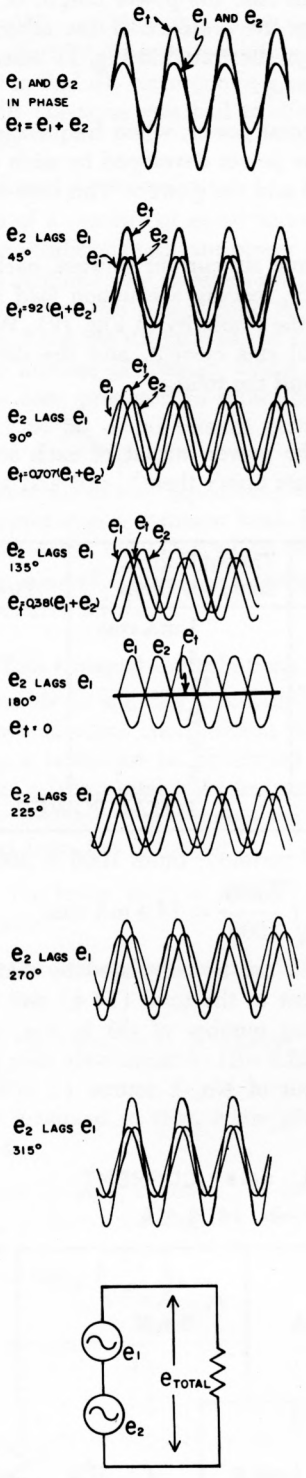


Figure 14. Two Voltages, Same Frequency, Different Phase.

and the power output of each source is the same as it would be if the other were not present. When the two sources have opposite phase (180°) they cancel each other, and the output is zero.

When the contributions from a number of sources add, and the relative phases are not known, it is not possible to determine the total. In some cases, when there are a great many contributions, it is reasonable to assume that Power Addition applies, as described below.

Power Addition—Different Frequencies

When two sine-waves have different frequencies, their phase relation changes constantly. This is illustrated by Fig. 15, which shows two sinusoidal voltages plotted on the same graph. Voltage e_2 has a lower frequency, so, as time progresses, e_2 lags ¼ cycle (90°) after e_1 has gone through 3 cycles; 180° after 6 cycles; and 360° (in other words back in phase again) after 12 cycles. If the time represented is one micro-second, e_1 has a frequency of 12 cycles/micro-second, or 12 MHz; and e_2 has a frequency of 11 MHz. It takes one micro-second for the phase relation between these two to progress through one full cycle, and the corresponding frequency, 1 MHz, is the difference between the two original frequencies (12 − 11 = 1).

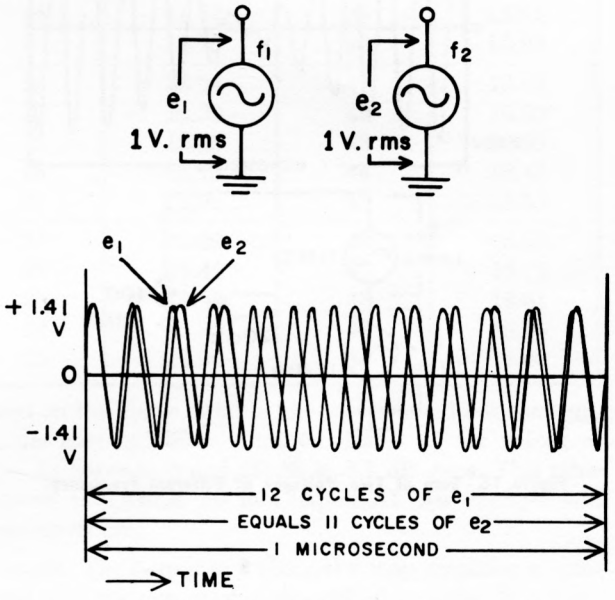


Figure 15. Two Voltages Having Different Frequencies.

When these two sources are connected in series, as illustrated in Fig. 16, the total voltage varies depending on their relative phase. When they are in phase the total reaches a peak of 2.82 volts (the sum of their peak voltages); as they shift, the total falls, going through zero when they have opposite phase, and back up to maximum when they are in phase again. They are said to "beat" with each other, and their difference frequency (in this case 1 MHz) is called the "beat frequency."

Now consider the power delivered to the 100-ohm load by these two sources. Since each one develops 1 volt rms it would, when connected to a 100-ohm load, deliver a power of 10 milliwatts. When both are connected in series, the power delivered to the load varies, as can be seen from the voltage waveform shown in Fig. 16. The power is a maximum when the two voltages are in phase, and zero

when they are at 180°. In other words, the power delivered varies as the two sine-waves beat with each other.

Inspecting the waveform of Fig. 16 it can be seen that the rms voltage is going to be less than 2 volts (which it would be if the two voltages were in phase all the time) and more than one volt (which it would be with either one alone). Actually it will be 1.41 volts, with a total power of 20 mW delivered to the load. A general rule applies:

When two or more sources supply voltage (or current) of different frequencies to a common load, the power delivered by each source is the same as that which would be delivered if all other sources were removed.

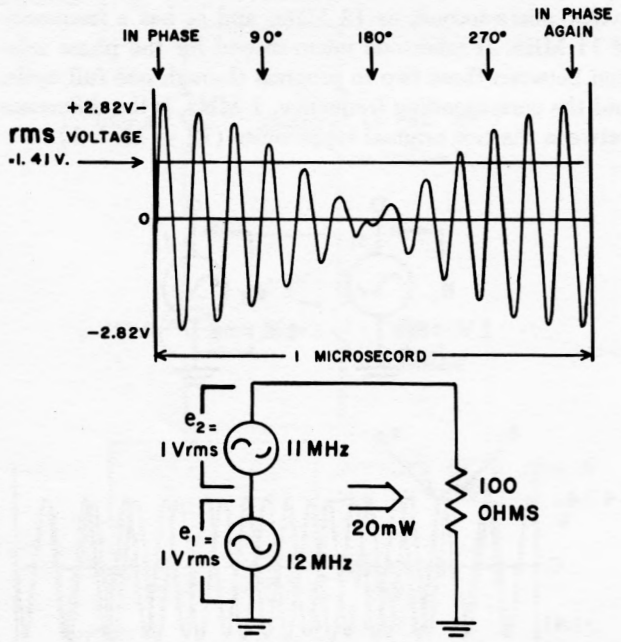


Figure 16. Sum of Two Voltages of Different Frequency.

Note that in this case the power output of each generator is unaffected by the presence of the other. Compare this with the situation illustrated in Fig. 11 where the two have the same frequency.

To derive the total power, when frequencies are different, we calculate the power developed by each source with the given load, and add the powers. This case is called "Power Addition."

Example: Assume six current sources, each having a different frequency, feeding a common load as illustrated in Fig. 17 (Note the similarity to Fig. 12). What is the total power, the total rms current, and the dB ratio between No. 1 current and the total.

Solution:

1. Calculate the power output of each source (pretending the others aren't there), and add to find the total power.

Source No.	Output Current Into 1000 Ohms	Power = I^2R
1	1 mA rms	1 mW
2	4	16
3	11	121
4	3	9
5	6	36
6	5	25
	TOTAL POWER	208 mW

2. Since (total current)^2 times 1000 = 208 mW, the total current is $\sqrt{\frac{0.208}{1000}} = 14.4$ mA rms.
3. The dB ratio can be calculated by taking the ratio of No. 1 current to the total (14.4) and looking up the corresponding number of dB in the current ratio-dB table V6 (23.2 dB). Alternatively take the ratio of the power output of No. 1 source (1 mW) to the total

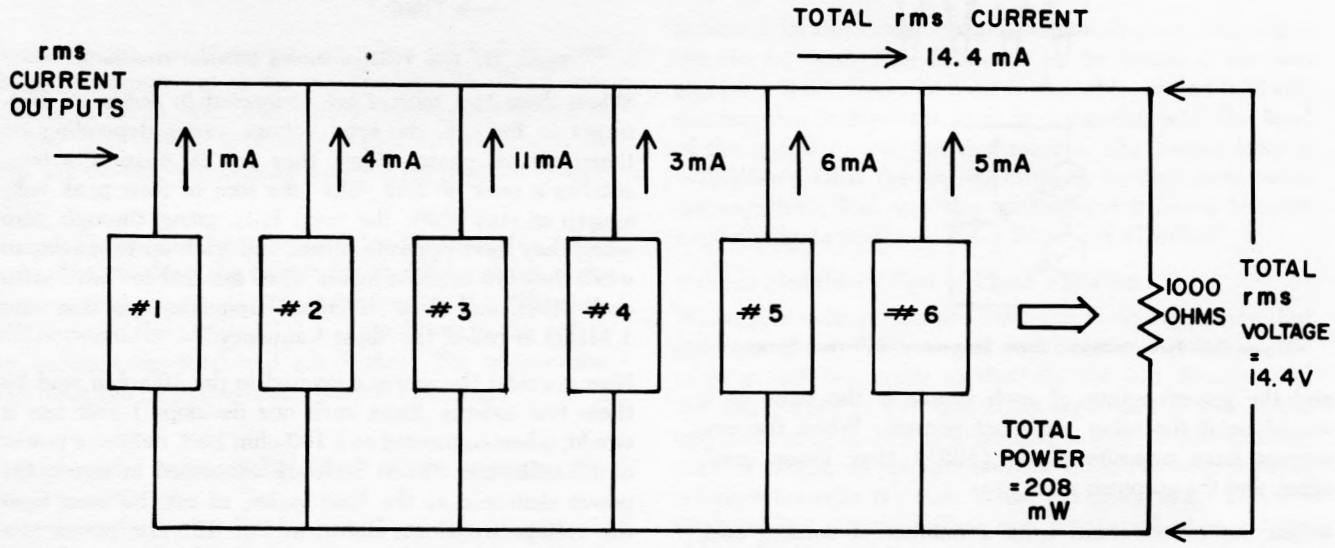


Figure 17. Addition of Current of Different Frequencies.

power (208 mW) and find the corresponding dB in the Power-dB chart P7. The power ratio would be 208. Divide by 100 to find dB corresponding to 2.08 (3.201) and add 20 dB (because you had to divide by 100) getting 23.2 dB.

Power Addition—Equal Contributions

When the outputs of a number of equal sources are to be combined, and the conditions indicate power addition, the calculation can be simplified by using a table. The table is prepared by noting that the power ratio is equal to the number of sources. Thus the dB ratio of the output level is 10 $\log_{10}$ times the number of sources. Using this relationship, Table G has been prepared to show the increase in output level for 1 to 50 equal sources combining on a power basis.

Example: 32 sources all having equal outputs and different frequencies combine in a common load. How much is the total output increased over that which would be supplied by a single source? Table G opposite 32 sources shows an increase of *15.05 dB*.

Power Addition—Two Unequal Contributions

Just as it was possible to simplify calculations by preparing a table for two unequal contributions in the case of Voltage Addition, a table can be developed for the case of Power Addition relating total level to input levels with two unequal contributions. The preparation of the table can be understood from the following:

Let L_s represent the lower level in dBmV, P_s the corresponding power ratio.

Let L_h represent the higher level in dBmV, P_h the corresponding power ratio.

Let L_t represent the total level in dBmV, P_t the corresponding power ratio.

We want a table arranged so that, when given $L_h - L_s$, we can find $L_t - L_h$.

By definition: $L_h = 10 \log_{10} P_h$ and $L_s = 10 \log_{10} P_s$,

hence: $L_h - L_s = 10 \log_{10} P_h - 10 \log_{10} P_s =$

$$-10 \log_{10} \left(\frac{P_s}{P_h} \right);$$

so given $L_h - L_s$ we can find $\frac{P_s}{P_h}$

Now, since: $P_t = P_s + P_h$ and $L_t = 10 \log_{10} (P_s + P_h)$,

hence: $L_t - L_h = 10 \log_{10} (P_s + P_h) - 10 \log_{10} P_h$

$$= 10 \log_{10} \frac{P_s + P_h}{P_h} = 10 \log_{10} \left(\frac{P_s}{P_h} + 1 \right);$$

Thus knowing $\frac{P_s}{P_h}$, we can simply add 1 to that number and then find the corresponding number of dB, representing $L_t - L_h$.

Example: let $L_h - L_s$ be 12 dB, then $\frac{P_s}{P_h} = 0.063$ and $\frac{P_s}{P_h} + 1 = 1.063$; then $L_t - L_h = 10 \log_{10} 1.063 = 0.265$ dB.

TABLE G

Number of Equal Contributions	dB Increase Corresponding to This Power Ratio	Number of Equal Contributions	dB Increase Corresponding to This Power Ratio
1	0	26	14.15
2	3.01	27	14.31
3	4.77	28	14.47
4	6.02	29	14.62
5	7.00	30	14.77
6	7.78	31	14.91
7	8.45	32	15.05
8	9.03	33	15.18
9	9.54	34	15.31
10	10.00	35	15.44
11	10.41	36	15.56
12	10.79	37	15.68
13	11.14	38	15.80
14	11.43	39	15.91
15	11.76	40	16.02
16	12.04	41	16.13
17	12.30	42	16.23
18	12.55	43	16.33
19	12.79	44	16.43
20	13.01	45	16.53
21	13.22	46	16.63
22	13.42	47	16.72
23	13.62	48	16.81
24	13.80	49	16.90
25	13.98	50	17.00

Based on the above, a table has been worked out showing, for the case of Power Addition, $L_t - L_h$ for values of $L_h - L_s$ between 0 and 20 dB in 0.1 dB steps. This table is given as TABLE P9 in Chapter XI. An example will illustrate its use.

Example: The output of a channel 6 strip amplifier is combined with the output of a channel 10 amplifier in a common load. Channel 6 level is +54 dBmV, channel 10 level is +64 dBmV. What is the total power output?

Solution: The level difference is 11 dB, so the amount to be added to the higher level (from TABLE P9) is 0.33 dB. The combined output level is +64.33 dB or about 36 milliwatts.

Power Splitting Relationships

In the analysis of CATV systems a situation is frequently encountered, particularly with regard to taps and splitters, where the power from a given source divides unequally between two loads. Given the dB ratio between the power from the source and the power in one load, we want to find the dB ratio between the source power and the power in the other load. This is another case of Power Addition, but the relationship is a little different from that described above, and another table is needed. Its preparation can be understood from the following:

Let L_s be the level of the lower one of the outputs, and P_s the corresponding power ratio

L_h be the level of the higher one of the outputs, and P_h the corresponding power ratio

L_t be the level of the input, and P_t the corresponding power ratio

We want a table arranged so that, when given $L_t - L_s$, we can find $L_t - L_h$.

By definition: $L_h = 10 \log_{10} P_h$ and $L_s = 10 \log_{10} P_s$

and since: $P_t = P_h + P_s$, $L_t = 10 \log_{10} (P_h + P_s)$,

hence: $L_t - L_s = 10 \log_{10} P_h + P_s - 10 \log_{10} P_s =$

$$= 10 \log_{10}\left(\frac{P_h + P_s}{P_s}\right) = 10 \log_{10}\left(\frac{P_h}{P_s} + 1\right)$$

Thus given $L_t - L_s$ we can find $\frac{P_h}{P_s}$;

but since $L_t - L_h = 10 \log_{10} (P_s + P_h) - 10 \log_{10} P_h =$

$$= 10 \log_{10}\left(\frac{P_s + P_h}{P_h}\right) = 10 \log_{10}\left(\frac{P_s}{P_h} + 1\right)$$

we first have to find $\frac{P_h}{P_s} - 1$, then invert to $\frac{P_s}{P_h}$, add 1, and then find the corresponding number of dB, representing $L_t - L_h$.

Example: let $L_t - L_s$ be 16 dB, then $\frac{P_h}{P_s} + 1 = 39.81$ and $\frac{P_h}{P_s} = 38.81$; inverted $\frac{P_s}{P_h} = 0.026$ and $\frac{P_s}{P_h} + 1 = 1.026$; then $L_t - L_h = 10 \log_{10} 1.026 = 0.1104$ dB.

A table P10 in Chapter XI has been prepared for the case of Power Splitting Relationships. An example will illustrate its use:

Example: A directional coupler divides energy between two output terminals. Assuming it has no internal power loss, and the loss to the tap output is 18 dB, what is the line loss?

Solution: In the table opposite 18 dB ($L_t - L_s$) we find 0.069 dB ($L_t - L_h$). So the line loss is *0.069* dB.

CHAPTER III

RANDOM NOISE IN CATV SYSTEMS

Fundamentals

In a CATV system, the lowest levels that can be allowed at antenna output terminals, at repeater inputs, or at the customer's set, without producing snowy pictures, are determined by thermal noise. An understanding of this noise, where it comes from and how strong it is, helps to understand system limitations.

Any resistor or source which looks resistive over the band in use (including antennas, amplifiers, or long cables) generates a thermal noise signal. In the case of a resistor this noise is due to the random motion of electrons, and its strength can be calculated.

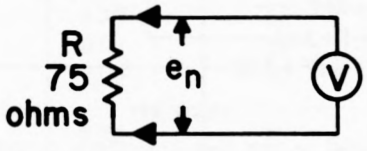


Figure 18.

If, as in Fig. 18, a sensitive high-impedance voltmeter (which generated no noise itself) could be connected across a 75-ohm resistor (or resistive source) it would measure an open-circuit noise voltage calculated by:

$$e_n = \sqrt{4\,R\,B\,k}$$

where e_n is the RMS noise voltage
R is resistance in ohms
B is the bandwidth of the voltmeter in MHz
k is a constant approximately equal to
40×10^{-16} at room temperature (68° F)

A reasonable bandwidth for TV is 4 MHz. Assuming this bandwidth, the open-circuited noise voltage for a 75-ohm resistor is:

$$e_n = \sqrt{4 \times 75 \times 4 \times 40 \times 10^{-16}}$$
$$= \sqrt{4.87 \times 10 - 12}$$
$$= \quad 2.2 \text{ microvolts RMS.}$$

If, as in Fig. 19, this source were connected to a 75-ohm load (which had no noise in itself) it would deliver half this voltage to the load:

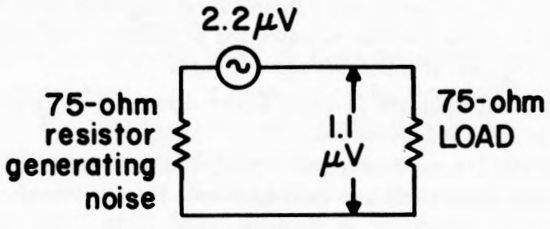


Figure 19.

Thus the noise input into 75 ohms is 1.1 microvolts RMS, or −59 dBmV. This is the basic noise level, the minimum that will exist in any part of a 75-ohm system.

Signal-to-Noise Ratio

In order to avoid snowy pictures, the signal, at any point in a system, must be sufficiently strong to override the noise.

This relationship is expressed by the "Signal-to-Noise Ratio," which is the difference between the signal level, measured in dBmV, and the noise level, also measured in dBmV; both levels being measured at the same point in the system.

Although the CATV industry has not reached agreement on the noise which can be tolerated in a picture signal, careful tests have been made by other organizations and much can be learned by considering the results.

Barstow and Christopher, of the Bell Telephone Laboratories, have published the results of careful studies on the subject.[1], [2] Their tests are summarized in terms of the signal-to-noise ratio which is rated "noise just perceptible" by the average judgment of a group of trained observers. The result which applies most nearly to the CATV situation is mentioned by Carson[3] referring to a picture viewed at eight times picture height with flat noise having a 4.2 MHz bandwidth. The given ratio, 39 dB, refers to the video signal (after detection) and corresponds approximately to an r-f ratio of 43 dB.

For comparison, consider the results of another series of tests conducted by the Television Allocations Study Organization (TASO) and published in their report to the FCC in 1959. Their ratings, corrected for a 4 MHz bandwidth instead of the 6 MHz they used, are shown below:

TASO Picture Rating	S/N Ratio
1. Excellent (no perceptible snow)	45 dB
2. Fine (snow just perceptible)	35 dB
3. Passable (snow definitely perceptible but not objectionable)	29 dB
4. Marginal (snow somewhat objectionable)	25 dB

(1) J. M. Barstow, and H. N. Christopher, "Measurement of Random Video Interference to Monochrome and Color TV," A.I.E.E. Transactions, Part I, Communications and Electronics, Vol. 63, Nov. 1962, pp. 313-320.

(2) J. M. Barstow and H. N. Christopher, "The Measurement of Random Monochrome Video Interference," A.I.E.E. Transactions, Part I, Communications and Electronics, Vol. 73, Jan. 1954, pp. 735-741.

(3) D. N. Carson, "CATV Amplifiers: Figure of Merit and the Coefficient System" 1966 IEEE International Convention Record, Part I, Wire and Data Communication, March 1966, pp. 87-97.

When it is decided how much noise is tolerable, the levels required in a system can be specified. With a signal-to-noise ratio of 43 dB, for example, the minimum signal level that would be required at the input to the first amplifier (if thermal noise were the only problem) would be $-59 + 43 = -16$ dBmV. Actual levels (to achieve this signal-to-noise ratio) must be quite a bit higher because of the noise that is contributed by the amplifiers.

Noise Figure

When a 75-ohm resistor is connected to the input of an amplifier having known gain, the noise output of the amplifier is **NOT,** as might be expected, the input noise (−59 dBmV) increased by the amplifier gain.

Since the amplifier always generates some internal noise, noise output is always greater than it would be from a noiseless amplifier having the same gain. This increase in noise output, expressed in dB, is called the "Noise Figure" of the Amplifier.

Consider, for example, an amplifier (Fig. 20) whose gain is known (from measurement with a signal) to be 40 dB. The measured noise output, with the input terminated, is −9 dBmV. What is the Noise Figure?

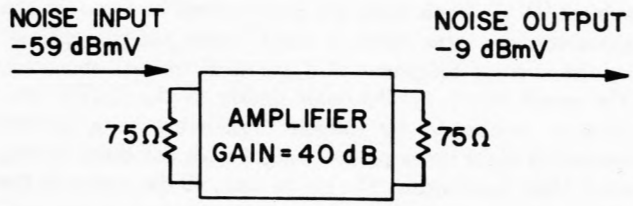


Figure 20.

If the amplifier had no internal noise, the noise output would be the input noise (dBmV) plus the amplifier gain (dB).

Noise output (no amp. noise) = −59 +40 = −19 dBmV. The measured noise is −9 dBmV, showing that the amplifier adds 10 dB to the noise output, and that the amplifier Noise Figure is 10 dB.

> *The Noise Figure of an amplifier or system is the difference between the measured output noise level (in dBmV) with a terminated input, and the thermal noise (−59 dBmV) plus the gain (in dB) of the amplifier.*

If an amplifier contributed no noise, the signal and the noise going through it would be amplified equally and the signal-to-noise ratio would be unchanged. Since the amplifier output contains added noise, as indicated by the Noise Figure, it follows that the Output Signal-to-Noise Ratio (in dB) is decreased as compared to the Input Signal-to-Noise Ratio. If the input noise is at the minimum level (−59 dBmV), that is if the input signal is noise free, the output Signal-to-Noise ratio (in dB) is found by subtracting the Noise Figure from the input Signal-to-Noise ratio.

Noise Figure in a Cascaded Amplifier System

General:

The trunk-line of a CATV system often consists of a series of nearly identical amplifiers equally spaced along a coaxial cable. Determining the increase in noise due to each amplifier in such a system helps to understand trunk line operation.

Two Amplifiers:

Consider two amplifiers having equal gain and noise figure, separated by a length of cable whose loss equals one amplifier's gain as shown in Fig. 21.

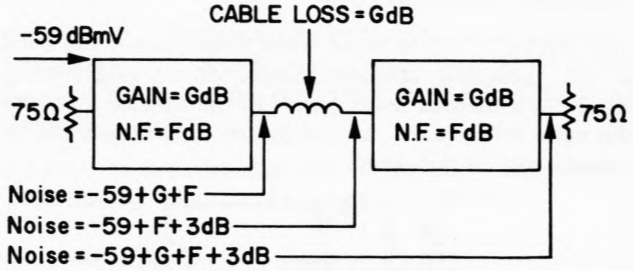


Figure 21.

The noise level at the first amplifier's output is thermal input noise (−59 dBmV) plus Gain (dB) plus Noise Figure (dB). The cable attenuates this noise back down to −59 +F, so that, in effect, there are two equal noise sources at the input of the second amplifier: the output of the first amplifier, attenuated by the cable, and the thermal noise at that point, including the equivalent noise of the second amplifier. Since the sum of two equal powers is 3 dB higher than either, the noise output from the second amplifier is increased 3 dB over that of the first. It follows that the noise figure of two identical amplifiers in cascade is 3 dB higher than the noise figure of each one. (See Note 1 on next page).

More Than Two Amplifiers:

By extending this logic it can be seen that, when a system is extended from two amplifiers to four amplifiers, the Noise Figure is again increased 3 dB and in general:

> *When identical amplifiers, connected by identical cable lengths whose individual losses equal one amplifier's gain, are cascaded, the system noise figure increases 3 dB each time the number of cascaded amplifiers is doubled.*

or stated mathematically:

$$F_m = F_1 + 10 \log_{10} m$$

where F_m is system noise figure, F_1 is amplifier noise figure and m is the number of cascaded amplifiers. The quantity "$10 \log_{10} m$" is called the cascade factor (C).

Since any increase in noise figure decreases the signal-to-noise ratio, it follows that:

> *With a noise-free input signal, the system signal-to-noise ratio decreases 3 dB each time the number of cascaded amplifiers is doubled* (See Note 2 on next page).

Table H can be used to find system noise figure or signal-to-noise ratio when these quantities are known for the individual amplifier.

To find the system noise figure for a given number of identical amplifiers in cascade: To the noise figure of an individual amplifier ADD the cascade factor found in the table opposite the number of amplifiers in cascade.

To find the system signal-to-noise ratio for a given number of identical amplifiers in cascade: From the signal-to-noise ratio at the output of the first amplifier SUBTRACT the cascade factor found in the table opposite the number of amplifiers in cascade (see Note 2 below).

TABLE H

No of Amps. in Cascade	Cascade Factor (C)	No of Amps. in Cascade	Cascade Factor (C)
1	0	26	14.15
2	3.01	27	14.31
3	4.77	28	14.47
4	6.02	29	14.62
5	7.00	30	14.77
6	7.78	31	14.91
7	8.45	32	15.05
8	9.03	33	15.18
9	9.54	34	15.31
10	10.00	35	15.44
11	10.41	36	15.56
12	10.79	37	15.68
13	11.14	38	15.80
14	11.43	39	15.91
15	11.76	40	16.02
16	12.04	41	16.13
17	12.30	42	16.23
18	12.55	43	16.33
19	12.79	44	16.43
20	13.01	45	16.53
21	13.22	46	16.63
22	13.42	47	16.72
23	13.62	48	16.81
24	13.80	49	16.90
25	13.98	50	17.00

Note 1:

The analysis on the preceding page for the case of two amplifiers in cascade is not very precise. An accurate analysis can be made based on three established facts:

(1) Noise factor (f) is related to noise figure (F) by: $F = 10 \log_{10} f$ (see page 72, par. 6)

(2) The noise factor for three devices connected in succession (output of the first to input of the second, etc.) is:

$$f_{123} = f_1 + \frac{f_2 - 1}{g_1} + \frac{f_3 - 1}{g_1 g_2}$$

Where: f_1, f_2 and f_3 are the noise factor of the first, second and third device, respectively.

g_1 and g_2 are the power gain of the first and second device, respectively.

(3) The power "gain" of an attenuating device is the ratio $\frac{\text{output power}}{\text{input power}}$, a number less than one. The noise factor of an attenuating device is the reciprocal of its power gain.

To apply these facts to the analysis of a cascade of two amplifiers assume that:

Device #1 is an amplifier. $f_1 = f_a$, $g_1 = g_a$

Device #2 is a length of cable whose loss is equal to the amplifier's gain

$$\text{so } g_1 g_2 = g_a g_2 = 1, \quad g_2 = \frac{1}{g_a} \text{ and } f_2 = \frac{1}{g_2} = g_a$$

Device #3 is an amplifier identical to #1 so $f_3 = f_a$, $g_3 = g_a$

Substituting these values in equation (2)

$$f_{123} = f_1 + \frac{f_2 - 1}{g_1} + \frac{f_3 - 1}{g_1 g_2} = f_a + \frac{g_a - 1}{g_a} + \frac{f_a - 1}{1} =$$

$$f_a + 1 - \frac{1}{g_a} + f_a - 1, \quad \text{so } f_{123} = 2 f_a - \frac{1}{g_a}$$

which says that the noise factor of two identical amplifiers in cascade is equal to twice the noise factor of one amplifier, less the reciprocal of its power gain. With noise factors of about 10 × (10 dB) and power gains of about 100 × (20 dB) it is apparent that the effect of the second term is negligible, so $f_{123} = 2 f_a$ or, in logarithmic terms, the noise figure of two identical amplifiers in cascade is 3 dB higher than the noise figure of each.

Note 2:

The "system signal-to-noise ratio" (in dB) is the difference (in dB) between the system's noise output level (in dBmV) with the input terminated, and the operating signal level at the output terminals (in dBmV).

Where the input signal is not noise-free, the noise it contains can be taken into account to find a total effective signal-to-noise ratio. This can be done for usual conditions by assuming that the total noise power output is the sum of two components: the noise power input increased by the system gain, and the noise power output of the system with its input terminated. In dB terms this is done by the method outlined on p. 72, par. 8, or as follows:

1. Take the difference between the S/N ratio (in dB) of the input signal at the first cascaded amplifier and the S/N ratio (also in dB) of the cascaded amplifier system.
2. Use chart P3 or table P9 to find the number of dBs to be subtracted from the smaller of the two ratios to find the total effective S/N ratio.

Example: System S/N ratio = 43 dB; Input S/N ratio = 47 dB; Difference = 47 − 43 = 4 dB; From table P9 opposite 4 dB find 1.46 dB. Thus total effective S/N ratio is: 43 − 1.46 = 41.4 dB.

CHAPTER IV

THE FUNDAMENTALS OF DISTORTION IN CATV AMPLIFIERS

Summary

This chapter presents an elementary introduction to the nature and effects of non-linear distortion in CATV amplifiers. Two forms of distortion are important: second order distortion which results, in extreme cases, in the compression of one peak of a sine-wave and the expansion of the other; and third order distortion which results, in the extreme case, in compression (or expansion) of both peaks. It is shown that the effects of second order distortion may be analyzed by an equation involving a linear term and a term proportional to the input voltage squared, while the effects of third order distortion can be analyzed by an equation including a linear term and a term involving the input voltage cubed.

In present CATV systems, second order distortion is generally not considered because, as will be shown, it results in distortion products at frequencies which are either sums, differences, or second harmonics of the carriers present and, with the standard frequency assignments, these products fall outside of the channels used.

Thus, the limiting factor in determining permissible output levels in most CATV amplifiers is third order distortion since it results in cross-modulation between channels, and beats between carriers which fall inside the channels being used.

Introduction

Distortion in sound reproducing equipment is familiar to anyone who has heard a worn-out juke box, or an overloaded public address system. This harsh, unpleasant sound presents the essential nature of all distortion: What comes out of the system is different from what went in! In CATV, distortion does not show up in the same way, but it is present, and it places restrictions on amplifier operation which must be understood if a system is to be intelligently planned and operated.

The amplifiers used in CATV have only one intended function: to raise the signal levels. The other things they do, the differences they generate between the outgoing signals and the incoming signals, are distortion. What forms does this distortion take? Several effects properly called distortion, such as the addition of noise to the signal, hum modulation and variations in amplifier frequency response are NOT the subject of this chapter. Here, we are concerned with only one kind of distortion: effects due to the same causes that create "harmonic distortion" in audio amplifiers.

This distortion is due entirely to non-linearity in the transfer characteristics of the transistors. Its worst aspect is cross-modulation, crossing over of the modulation from one channel to another, which causes "windshield wiper" effects in the picture. Other effects include harmonics, where an unwanted signal is generated at a frequency which is some multiple of the frequency of a wanted one; and beats, where two or more wanted signals combine to generate an interfering one. These harmonics and beats can combine with the carrier on the channel in use to cause "herringbone" patterns in the picture. A study of this type of distortion will help in understanding how CATV amplifiers can be operated to avoid these problems.

Distortionless Amplification

Perhaps the simplest way to describe amplifier distortion is to say what it is NOT. A distortionless amplifier would be one which increased the amplitude (voltage swing) of the input signal without changing its waveform. Suppose, for example, an amplifier could be built so that the output voltage, at each instant, was exactly 10 times the input voltage. A graph showing the output voltage plotted against the input voltage would be a straight line, as illustrated in Fig. 22. Such a graph is called the "transfer characteristic" or "input-output curve," for the amplifier. A transfer characteristic which is a straight line is called a "linear transfer characteristic."

Mathematically, the performance of this amplifier would be described by the equation: $e_{out} = 10\ e_{in}$; where e_{out} is the instantaneous output voltage, and e_{in} is the instantaneous input voltage. Calculating for particular voltages would give a table:

e_{out} (= 10 e_{in})		e_{in}	e_{out} (= 10 e_{in})
0	0	0	0
−0.2	−2	+0.2	+2
−0.4	−4	+0.4	+4
−0.6	−6	+0.6	+6
−0.8	−8	+0.8	+8
−1.0	−10	+1.0	+10

This is the table from which the characteristic of Fig. 22 is plotted.

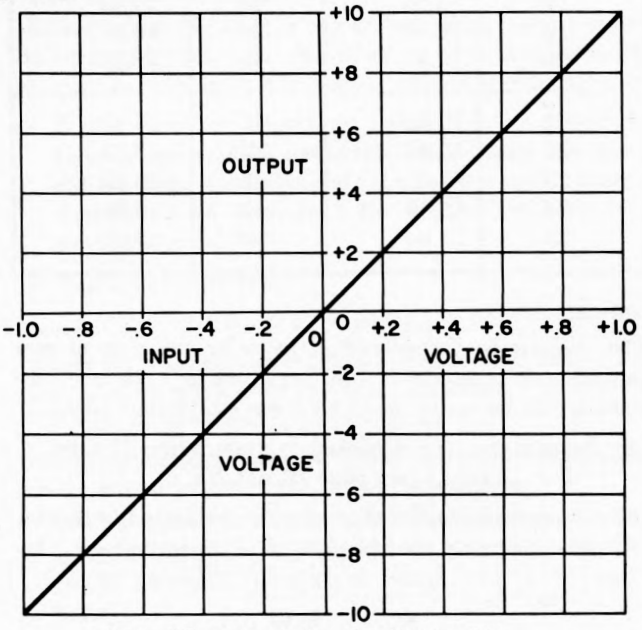


Figure 22. A Linear Transfer Characteristic

The way in which such a linear transfer characteristic results in an undistorted output is shown in Fig. 23. A plot of the sinusoidal input voltage against time is illustrated [Fig. 23(a)]. If, at each point along the time scale, the instantaneous input voltage is projected downward to the transfer characteristic [Fig, 23(b)], the corresponding output voltage is found. Projecting this to the right, and plotting against the same time scale, constructs graphically the waveform of the output voltage [Fig. 23(c)]. For example, when the input is 0.75 volts and decreasing (point "A"), the output is 7.5 volts and decreasing (point "B"). Since the output voltage at any time is simply ten times the input voltage, the output duplicates the input waveform.

Distortionless amplification does not require that the input be a pure sinusoidal voltage. It is achieved when the waveform of the output voltage precisely duplicates that of the input, regardless of what that waveform may be. Fig. 24, for example, presents a diagram similar to Fig. 23 except with a pyramidal input, showing how an identically-shaped pyramidal output results.

Amplification with Distortion

Unfortunately, amplifiers that can be built using real-life transistors do not have a linear relationship between the input voltage and output voltage. Figure 25 illustrates a non-linear transfer characteristic which might be found in a real amplifier. As the input voltage swings either way from 0, the output changes along a curve which produces less and less change in output voltage as the input swings further and further from 0. If, in Fig. 25, the output would continue to increase almost linearly, as it does between 0 and 4 V, it would reach about 20 V for a 1-V input instead of 10 V as shown.

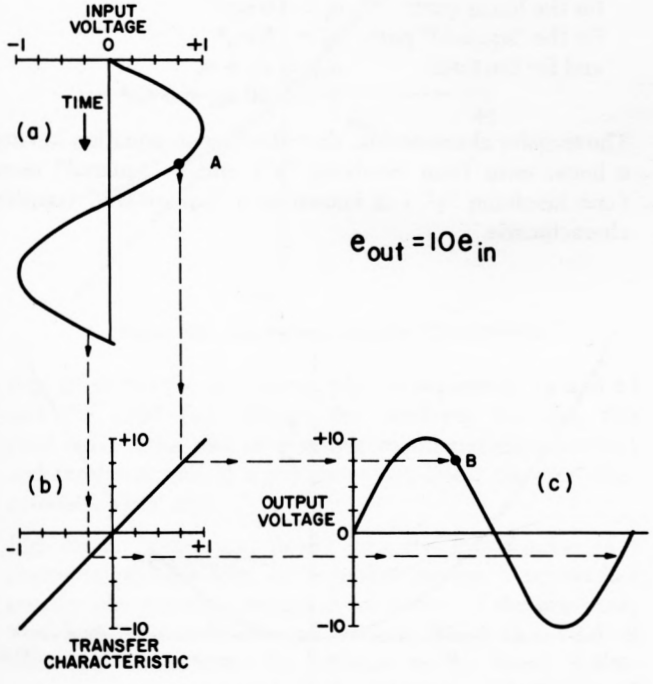


Figure 23. Distortionless Amplification.

When a varying voltage is applied to an amplifier with a characteristic of this sort, the output voltage has a different waveform than the input voltage. Consider the examples shown in Figure 26. Figure 26(a) illustrates the output voltage waveform obtained when a sinusoidal voltage with a voltage swing between +1 and −1 volt is applied to the amplifier whose characteristic is illustrated in Figure 25. Since the transfer characteristic is symmetrical, both peaks of the output voltage are flattened by the non-linearity, giving the waveform illustrated.

A 1.0 volt peak-to-peak sinusoidal voltage applied to the input of the same amplifier and biased at −0.5 volts so

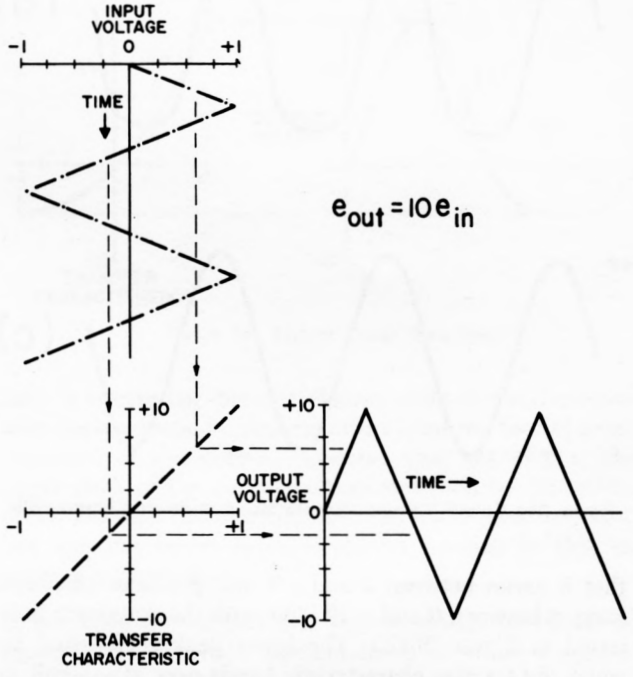


Figure 24. Distortionless Amplification.

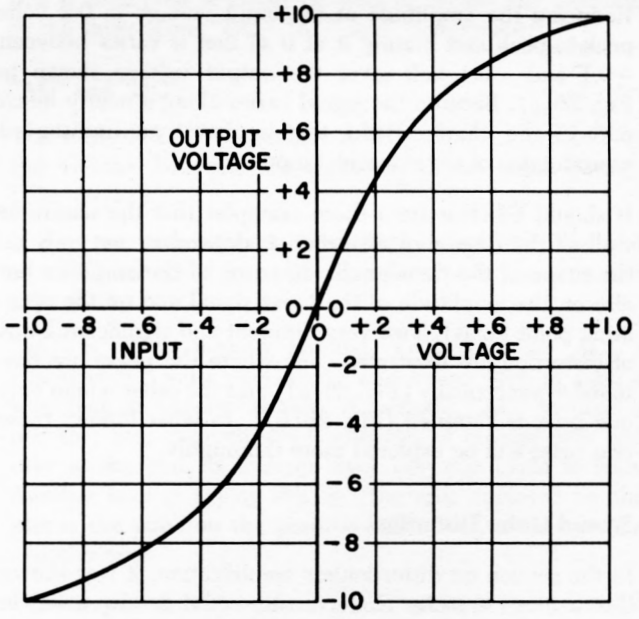


Figure 25. A Non-linear Transfer Characteristic.

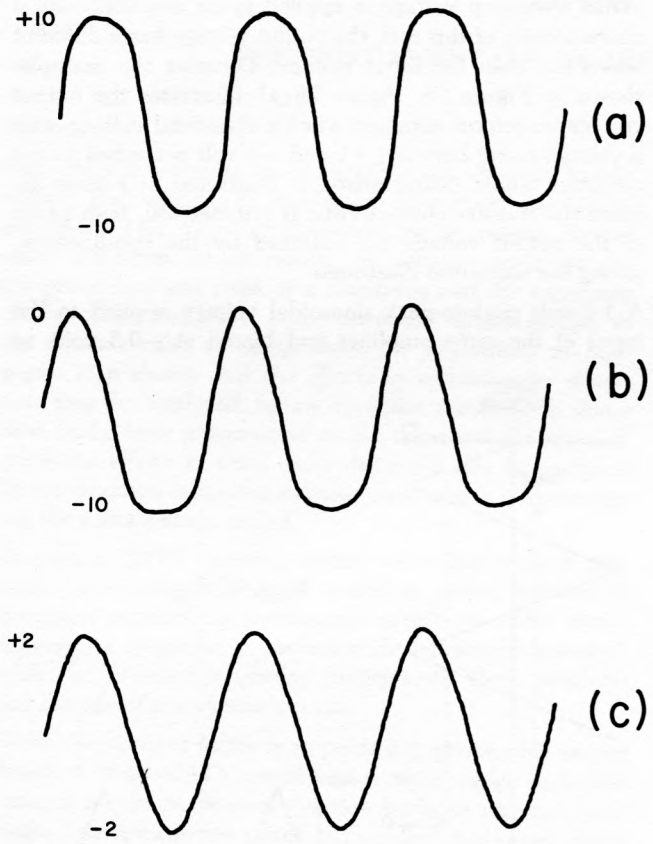


Figure 26. Output Voltage Waveforms, Non-linear Characteristic.

that it varies between 0 and −1 volt produces an output varying between 0 and −10 volts with the waveform illustrated in Figure 26(b). The lower peak is flattened because the transfer characteristic bends over at −1 volt input; the upper peak is faithfully reproduced because the characteristic is very nearly a straight line near 0.

Reducing the amplitude of the input voltage to 0.2 volts peak-to-peak and biasing it at 0 so that it varies between +0.1 and −0.1 volt gives the output voltage shown in Fig. 26(c). Because the signal varies along a nearly linear part of the characteristic, this is almost an undistorted reproduction of the sinusoidal input.

It should be clear from these examples that the nature as well as the degree of distortion is dependent not only on the shape of the transfer characteristic of the amplifier but also on the amplitude of the input signal and on the operating point (bias). Two very different and significant kinds of distortion are illustrated: one where the peaks are flattened symmetrically [Fig. 26(a)] and the other where only one peak is flattened [Fig. 26(b)]. In what follows these two cases will be explored more thoroughly.

Second Order Distortion

In the section on distortionless amplification, it was shown that a linear transfer characteristic could be expressed in very simple mathematical terms. The equation "$e_{out} = 10\ e_{in}$" says very clearly that the amplifier in question has a gain of ten times and no distortion. Since all practical amplifiers cause distortion, a sensible question is: "Can the transfer characteristic of a practical amplifier be expressed in some simple mathematical way which will allow analysis of the distortion generated?" The answer is that the transfer characteristic of a practical amplifier can be approximated by a simple mathematical expression and the subject of what follows is how this is done.

First, consider an amplifier which generates the kind of distortion illustrated in Figure 26(b). The transfer characteristic causing this kind of distortion can be approximated by an equation having the form "(e_{out}) equals (some number × e_{in}) plus (some other number × e_{in}^2)."

The following may help to understand how this works. Consider first the curve that results when e^2 is plotted against e; the numbers are tabulated below.

e	e^2	e	e^2
−1.0	+1.0	+1.0	+1.0
−0.8	+0.64	+0.8	+0.64
−0.6	+0.36	+0.6	+0.36
−0.4	+0.16	+0.4	+0.16
−0.2	+0.04	+0.2	+0.04
0	0	0	0

The corresponding curve is plotted in Figure 27. Notice that it is symmetrical around the vertical axis, curving up smoothly for both positive and negative magnitudes of e.

Next consider an example of what happens when such a curve is added to a linear transfer characteristic. The output voltage is separated into two parts:

for the linear part: $e_1 = 10\ e_{in}$
for the "squared" part: $e_2 = 5\ e_{in}^2$
and for the total: $e_{out} = e_1 + e_2$
$= 10\ e_{in} + 5\ e_{in}^2$

The transfer characteristic described by an equation having a linear term (one involving "e") and a "squared" term (one involving "e^2") is known as a "square-law" transfer characteristic.

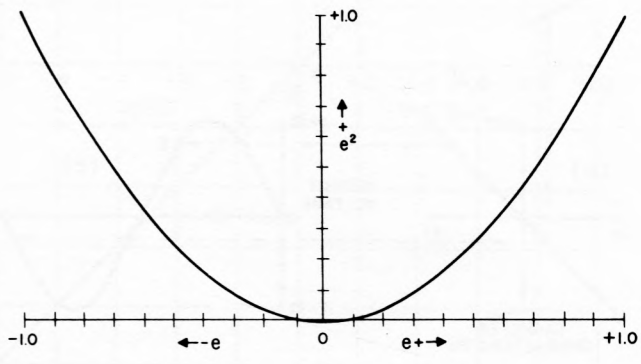


Figure 27. e^2 Plotted Against e.

The numbers are tabulated below:

e_{in}	$10\ e_{in}$	e_{in}^2	$5\ e_{in}^2$	$10\ e_{in} + 5\ e_{in}^2$
−1.0	−10	+1.0	+5.0	− 5.0
−0.8	− 8	+0.64	+3.2	− 4.8
−0.6	− 6	+0.36	+1.8	− 4.2
−0.4	− 4	+0.16	+0.8	− 3.2
−0.2	− 2	+0.04	+0.2	− 1.8
0	0	0	0	0
+0.2	+ 2	+0.04	+0.2	+ 2.2
+0.4	+ 4	+0.16	+0.8	+ 4.8
+0.6	+ 6	+0.36	+1.8	+ 7.8
+0.8	+ 8	+0.64	+3.2	+11.2
+1.0	+10	+1.00	+5.0	+15.0

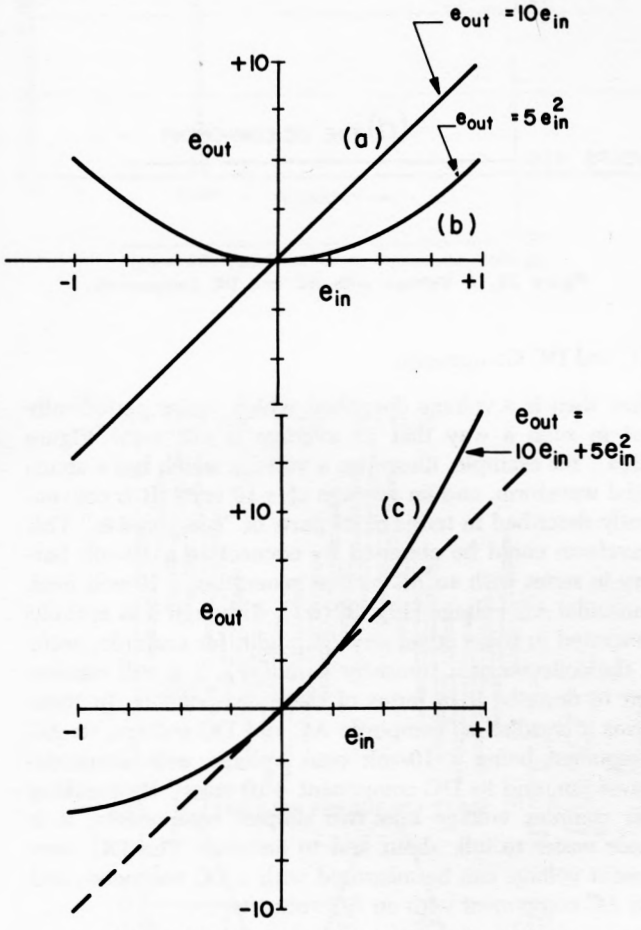


Figure 28. Square-law Transfer Characteristic.

Fig. 28 shows the two curves plotted separately (a and b) and the total (c). Notice the similarity between this total curve (the plot of a simple mathematical equation) and the lower half of a particular non-linear transfer characteristic (Fig. 25).

Fig. 29 illustrates graphically how the introduction of a sinusoidal voltage into an amplifier having a square-law transfer characteristic results in an output of the one-peak-stretched, one-peak-flattened variety. Since this kind of distortion results from the addition to the linear characteristic of a quantity involving e^2, it is called "second order" distortion. In these terms it is said that Fig. 29 shows

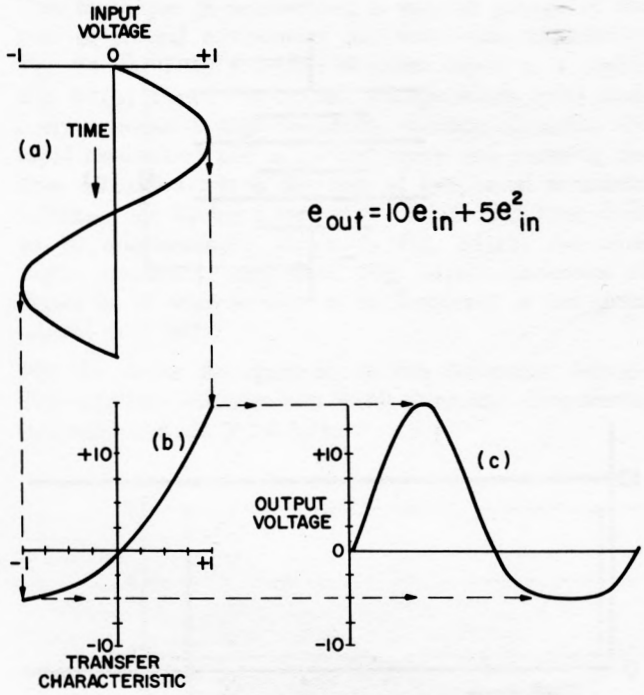


Figure 29. Second Order Distortion.

that "a square-law transfer characteristic (or a characteristic having second-order curvature) causes second-order distortion of the output." Observe that not only is the upper peak of the output voltage stretched by the action of the second-order distortion and the lower peak flattened, but also the entire curve is shifted upward so that its average is above 0.

It has been shown that one way to study the effects of second-order distortion mathematically is to use a square-law equation. There is a second approach which is also very useful. This involves the addition of DC and AC component voltages to produce a distorted total. Before this is presented it might be well to review the meaning of the three terms "DC," "AC" and "component."

"AC" and "DC"

The idea of "DC" is familiar. A DC voltage is typified by the voltage between the terminals of an ideal battery [Fig. 30(a)].

It does not vary either in magnitude or polarity. The plot of a DC voltage is a straight line parallel to the time axis [Fig. 30(b)].

"AC" is almost equally familiar. To qualify as "AC" a characteristic must vary above and below zero in such a way that its average is zero. A periodic "AC" voltage is one that goes through identical cycles of change over and over again, and its average over any one cycle is zero. Another way of saying this is: "the area enclosed by the plot is the same on the positive half-cycles as that on the negative ones."

Figures 31(a), (b) and (c) all represent periodic AC voltages, since in each case the variation is repeated in identical cycles and the average is zero. To see how the

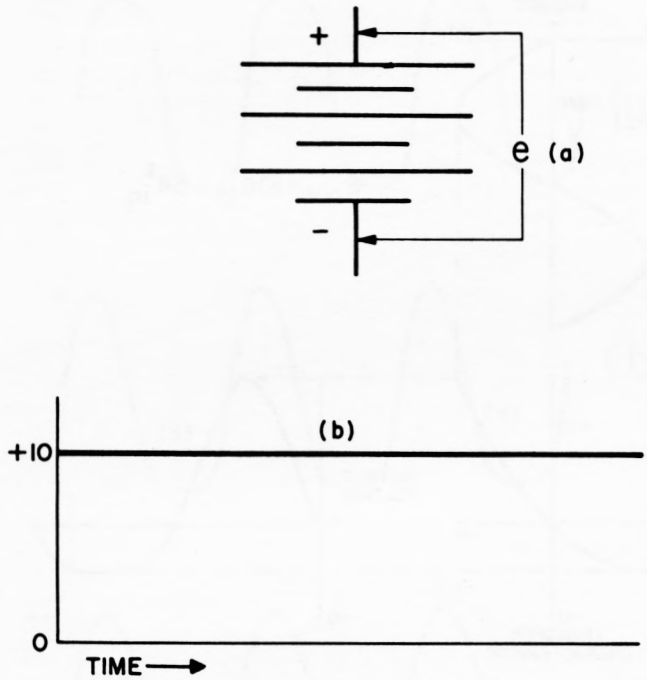


Figure 30. DC Voltage.

average is zero, imagine a DC voltmeter reading each of these voltages. Assuming the change to be faster than the needle can follow, it would be pushed equally in both directions, so would read zero.

VOLTAGE IS AC WHEN AREA "X" = AREA "Y"

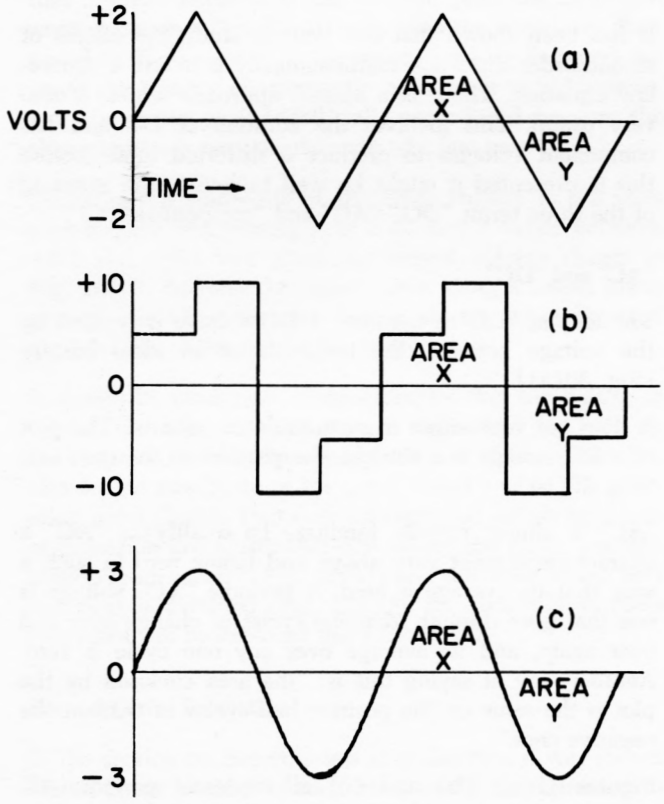


Figure 31. Three AC Voltages with Different Waveforms.

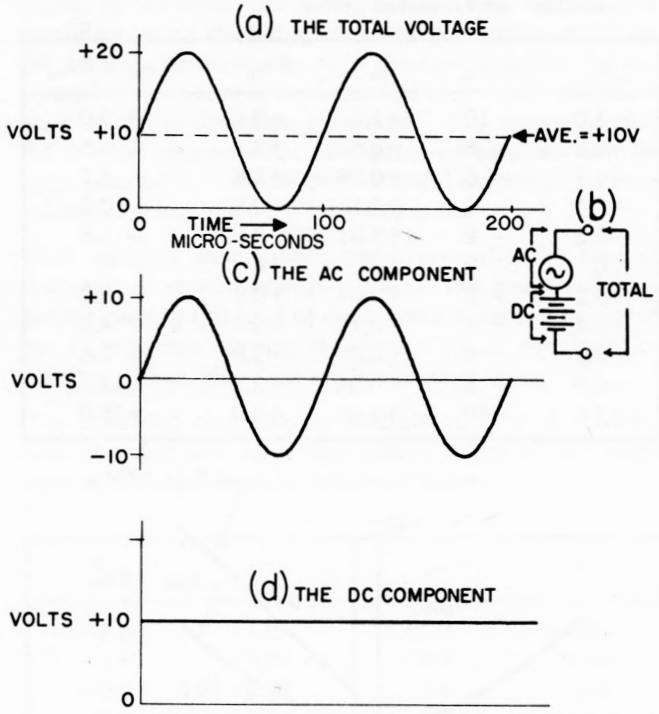


Figure 32. A Voltage with AC and DC Components.

AC and DC Components

How then is a voltage described which varies periodically but in such a way that its average is not zero? Figure 32(a), for example, illustrates a voltage which has a sinusoidal waveform, and an average of +10 volts. It is conveniently described in terms of its parts or "components." This waveform could be obtained by connecting a 10-volt battery in series with an AC source generating a 10-volt peak sinusoidal AC voltage [Fig. 32(b)]. Although it is actually generated in some other way (it might, for example, occur at the collector of a transister amplifier), it is still convenient to describe it in terms of these components. In these terms it is called a "composite AC and DC voltage, its AC component being a 10-volt peak voltage with sinusoidal waveform, and its DC component +10 volts." By breaking this complex voltage into two simpler components, it is made easier to talk about and to measure. The DC component voltage can be measured with a DC voltmeter, and the AC component with an AC voltmeter.

The Spectrum of a Composite Voltage:

When a periodic varying voltage contains several components like this, it can be conveniently analyzed by plotting its "spectrum." A spectrum is simply a graph which plots, in the vertical direction, the peak voltage or amplitude of each component and, in the horozinotal direction, the frequency at which each of these components exists. Its importance rests on the fact that "spectrum analyzers" are available which plot these diagrams automatically, providing tremendously useful tools for distortion analysis.

The spectrum of a sinusoidal voltage is a single spike showing the amplitude and frequency of that voltage.

Fig. 33 shows the spectrum of the composite voltage whose waveform is plotted in Fig. 32(a). The spectrum contains the same information as the time plot. It says that this voltage consists of two components, a DC component of 10 volts (represented by the 10-volt spike at 0 frequency) and a sinusoidal component of 10 volts peak amplitude at a frequency of 10 kHz (represented by the 10-volt spike at 10 kHz).

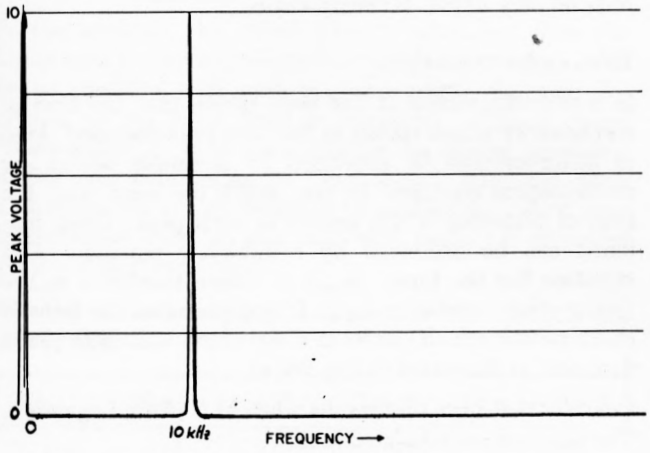


Figure 33. Spectrum of a Composite Voltage.

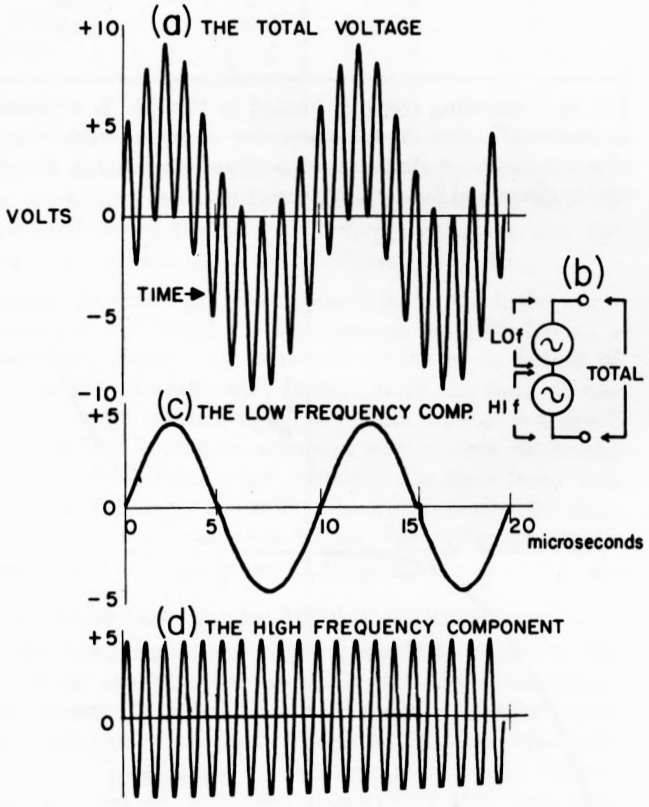


Figure 34. A Voltage with Two Sinusoidal Components.

A Voltage with Two AC Components

This technique of representing a varying voltage as the sum of several components has very wide application. Fig. 34 illustrates a second situation where it is useful. Fig. 34(a) shows a composite voltage which quite obviously contains a high-frequency variation (causing the rapid oscillation) and a low-frequency one (causing the slow oscillation). It is the sum of two equal sinusoidal voltages; one having a frequency of 100 kHz (one cycle in 10 microseconds) shown in Fig. 34(c); the other higher frequency component, Fig. 34(d), completes 10 cycles in 10 microseconds so its frequency is ten times higher, or 1 MHz.

Fig. 35 shows the spectrum of this composite voltage. The spectrum indicates two 5-volt sinusoidal components, one at 0.1 and one at 1.0 MHz.

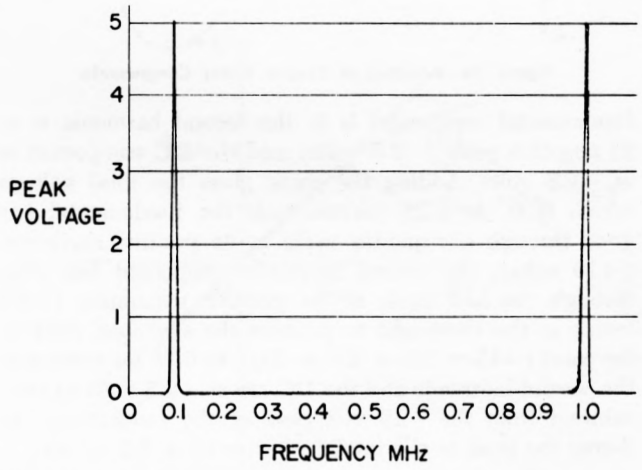


Figure 35. Spectrum of Voltage with Two AC Components.

Second Order Distortion by Addition of Components

The use of sinusoidal components to represent a non-sinusoidal varying voltage has its most important application in the study of distortion. Earlier we discussed the distortion produced when a sinusoidal input is applied to an amplifier with second order distortion.

The waveform resulting from this distortion is plotted in Fig. 29(c). An identically distorted waveform can be formed by adding sinusoidal components (or, conversely such a waveform can be separated into sinusoidal components). Fig. 36 illustrates the process.

This diagram shows how a distorted output can be generated by adding three components: the FUNDAMENTAL component, a sinusoidal voltage having a frequency of 1 MHz (1 cycle in 1 microsecond) in this example; the SECOND HARMONIC component, a sinusoidal voltage having twice this frequency, 2 MHz (2 cycles in 1 microsecond); and a positive DC component.

Notice first that the total voltage has a waveform identical to that shown in Fig. 29(c) (the one produced when a sinusoidal voltage is passed through an amplifier with a square-law characteristic). Now see how the three components add in Fig. 36: At 0 time on the diagram, the

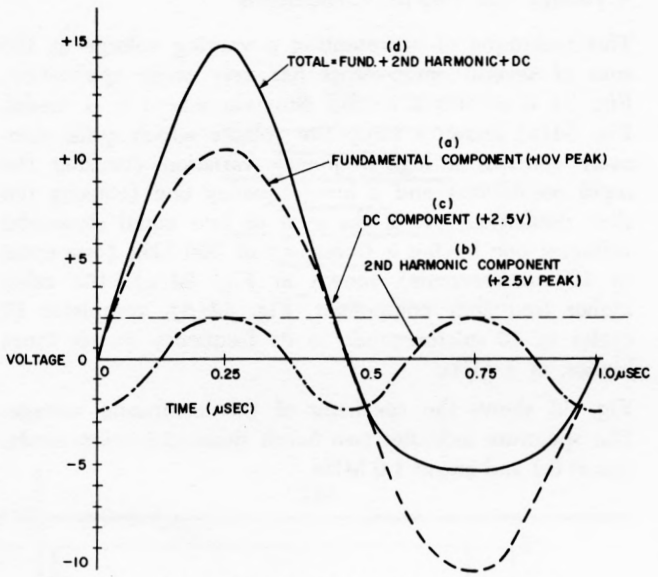


Figure 36. Addition of Second Order Components.

fundamental component is 0, the second harmonic is at its negative peak (−2.5 volts) and the DC component is at +2.5 volts. Adding the three gives the total voltage which is 0. At 0.25 microseconds the fundamental has gone through one-quarter cycle to its positive maximum (+10 volts), the second harmonic component has gone through one-half cycle to its positive maximum (+2.5 volts) so the three add to produce the stretched peak of the total (+15 = 2.5 + 2.5 + 10). At 0.75 microseconds the second harmonic and the DC are at +2.5 volts so they subtract from the −10 volt peak of the fundamental to flatten the peak of the total (−5 = −10 + 2.5 +2.5).

Figure 36 illustrates one case of a very important general principle: *Any non-sinusoidal periodic waveform can be produced by an appropriate combination of DC and sinusoidal components.*

The Spectrum of a Voltage with Second Order Distortion

The distorted voltage of Fig. 29(c) and Fig. 36(d) can also be represented by the spectrum diagram shown in Fig. 37. This shows the three components that make it up:

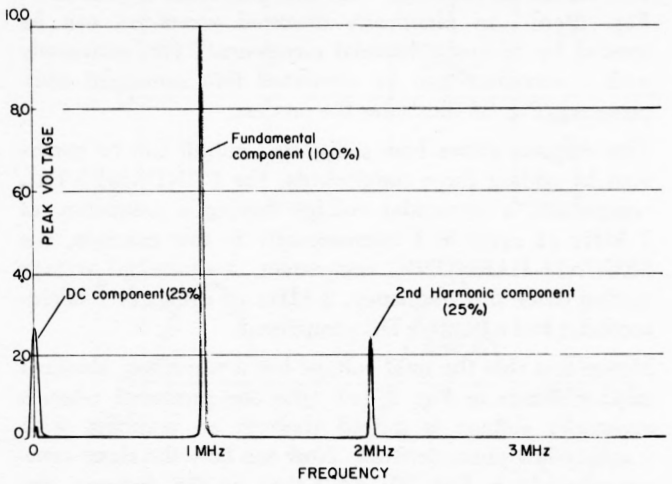


Figure 37. Spectrum Analysis Showing 2nd Order Distortion.

a 2.5-volt DC component, a 10-volt peak 1-MHz component (the fundamental) and a 2.5-volt 2-MHz component (the second harmonic). Some points should be noted in regard to these diagrams. Each spike on a spectrum diagram ALWAYS represents a pure sinusoidal component. If a periodic voltage is non-sinusoidal, its spectrum shows more than one component. When a DC component exists, it does not appear on the spectrum displayed by the usual spectrum analyzer. The input circuits of most analyzers respond only to the AC components.

Third Order Distortion

In a previous section it has been shown that the kind of non-linearity which results in the "one-peak-flattened" kind of distortion can be expressed by a simple square-law mathematical equation. In very much the same way, the kind of distortion which results in both peaks being flattened can be expressed by a cube-law equation. This equation has the form: $(e_{out}) = (\text{some number} \times e_{in}) - (\text{some other number} \times e_{in}^3)$. It approximates the transfer characteristic which results in a waveform with both peaks flattened, as illustrated in Fig. 26(a).

Consider the curve that results when e^3 is plotted against e. The numbers are tabulated here.

e	e^3	e	e^3
−1.0	−1.000	+1.0	+1.000
−0.8	−0.512	+0.8	+0.512
−0.6	−0.216	+0.6	+0.216
−0.4	−0.064	+0.4	+0.064
−0.2	−0.008	+0.2	+0.008
0	0	0	0

The corresponding curve is plotted in Fig. 38. It is "skew symmetrical"; that is, the curve for negative magnitudes of e has the same shape as for positive magnitudes, but is upside down and has opposite direction.

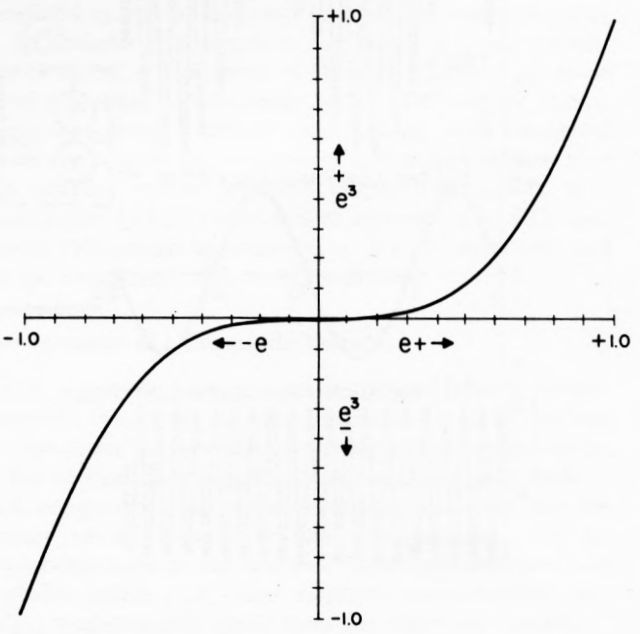


Figure 38. e^3 Plotted Against e.

When this curve is added to a linear transfer characteristic, it affects both extremes in the same way, since the linear part and the "cubed" part go positive together and negative together. Consider an example:

Let the linear part of the characteristic be: $e_1 = 10\ e_{in}$ and the "cubed" part be: $e_3 = 3\ e_{in}^3$.

To get a curve which flattens the peaks, the cubed part is subtracted from the linear part, so the total is:

$$e_{out} = e_1 - e_3 = 10\ e_{in} - 3\ e_{in}^3$$

In this example, the cubed term is subtracted from the linear term to give a characteristic which flattens the peaks. In an amplifier with such a characteristic, the gain decreases as the input level is increased. (This is called "compression.") It is also possible to design amplifiers whose gain increases as the input level is increased. Such a characteristic is approximated by *adding* the cubed term to the linear term. In this case both peaks are stretched (this is called "expansion").

For the above example of compression the numbers are tabulated here.

e_{in}	$10\ e_{in}$	e_{in}^3	$3\ e_{in}^3$	$10\ e_{in} - 3\ e_{in}^3$
−1.0	−10	−1.000	−3.000	−7.000
−0.8	− 8	−0.512	−1.536	−6.464
−0.6	− 6	−0.216	−0.648	−5.352
−0.4	− 4	−0.064	−0.192	−3.808
−0.2	− 2	−0.008	−0.024	−1.976
0	0	0	0	0
+0.2	+ 2	+0.008	+0.024	+1.976
+0.4	+ 4	+0.064	+0.192	+3.808
+0.6	+ 6	+0.216	+0.648	+5.352
+0.8	+ 8	+0.512	+1.536	+6.464
+1.0	+10	+1.000	+3.000	+7.000

Fig. 39 shows the two component curves plotted separately (a and b) and the total (c). Notice the similarity between this total curve, the plot of a simple equation, and the non-linear transfer characteristic shown in Fig. 25.

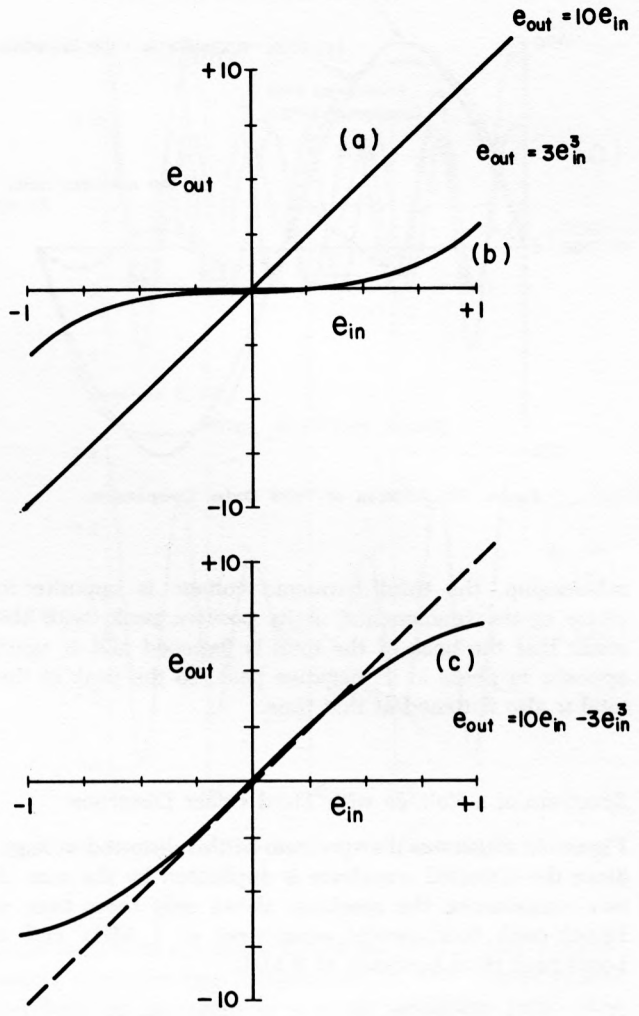


Figure 39. Cube Law Transfer Characteristic.

Fig. 40 illustrates graphically the way in which the introduction of a sinusoidal voltage into an amplifier having a "cube-law" transfer characteristic results in an output of the "both-peaks-flattened" variety. Since this kind of distortion results when a signal is passed through a transfer characteristic having an equation with a term containing e^3, it is called "third order" distortion. In these terms it is said that Figure 40 shows that "a cube-law transfer characteristic (or a characteristic having third order curvature) causes third order distortion of the output."

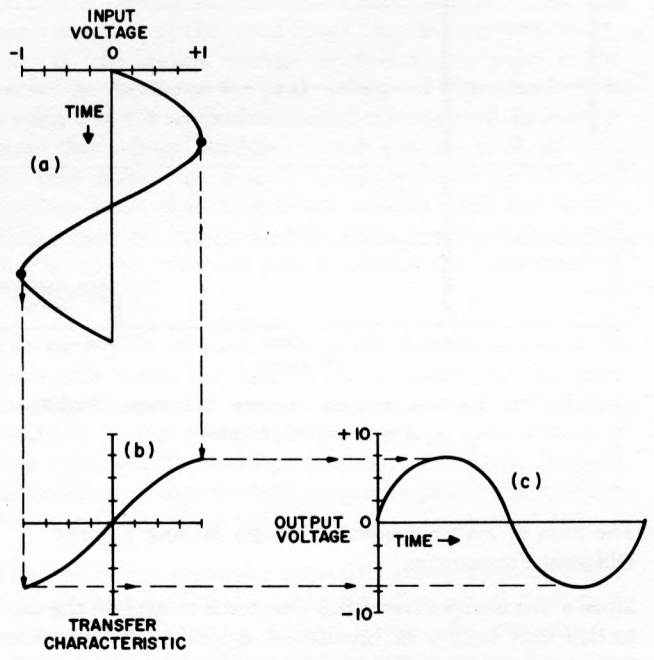


Figure 40. Third Order Distortion.

Third Order Distortion by Addition of Components

In the foregoing it was found possible to duplicate the effects of second order distortion by adding sinusoidal components. In a similar way, the effects of third order distortion can be obtained. Figure 41 illustrates the addition of a 10-volt peak, 1-megahertz fundamental component (a) and a 1-volt peak, 3-megahertz third harmonic component (b) to produce a distorted total (c) having the same waveform as that generated by the cube-law equation illustrated in Fig. 40(c). Because of the 3:1 frequency

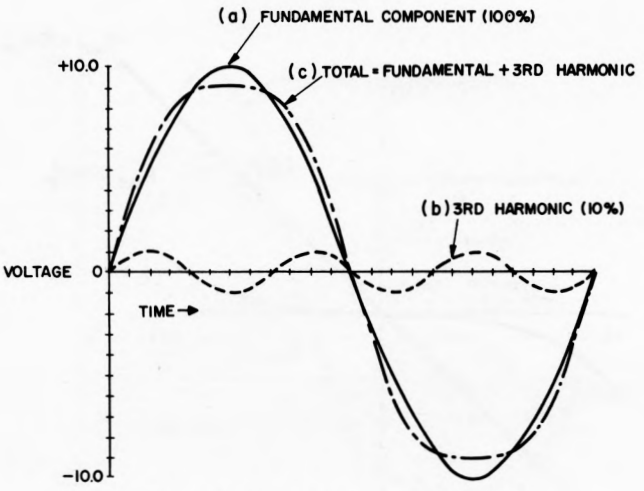


Figure 41. Addition of Third Order Components.

relationship, the third harmonic voltage is opposite in phase to the fundamental at its positive peak, with the result that the peak of the total is flattened and is again opposite in phase at its negative peak, so the peak of the total is also flattened at that time.

Spectrum of a Voltage with Third Order Distortion

Figure 42 illustrates the spectrum of this distorted voltage. Since the distorted waveform is duplicated by the sum of two components, the spectrum shows only these two: a 10-volt-peak fundamental component at 1 MHz and a 1-volt-peak third harmonic at 3 MHz.

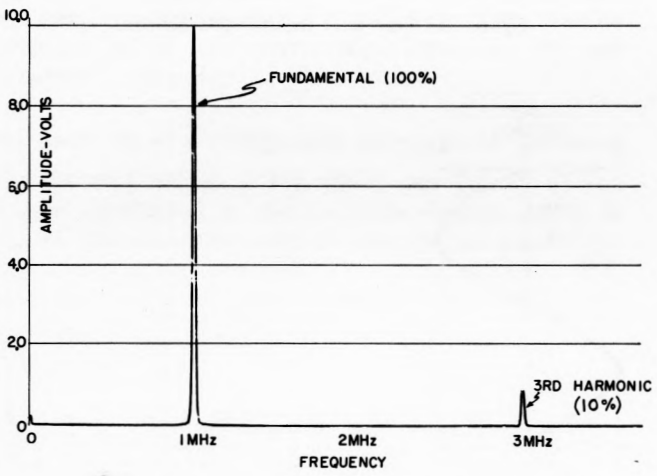


Figure 42. Spectrum Analysis Showing 3rd Order Distortion of a Sinusoidal Voltage.

The Sum of Two Sinusoidal Voltages Having Slightly Different Frequencies

Since a major objective of this chapter is to explain the distortion that occurs in broadband amplifiers when many "channels" are handled simultaneously, it is necessarily concerned with what happens in an amplifier when more than one sinusoidal voltage is introduced into it. Although the picture carrier on each channel is not a constant-amplitude sine-wave (since it is modulated with the picture information), by temporarily pretending that it is, we can learn a great deal about the nature of distortion in this case.

The first question then is: What is the waveform resulting when two sine-waves having slightly different frequencies are added? The two television carriers are said to have SLIGHTLY different frequencies because in general their frequency separation is small compared with their frequencies. (In contrast to the case illustrated in Fig. 34 where one frequency is ten times the other.)

To answer this question it is helpful first to consider the way in which two sinusoidal voltages add when both have the same frequency and amplitude, but have various phase relationships. Fig. 43 illustrates several cases showing each voltage separately (a and b) and the resulting total voltage (c).

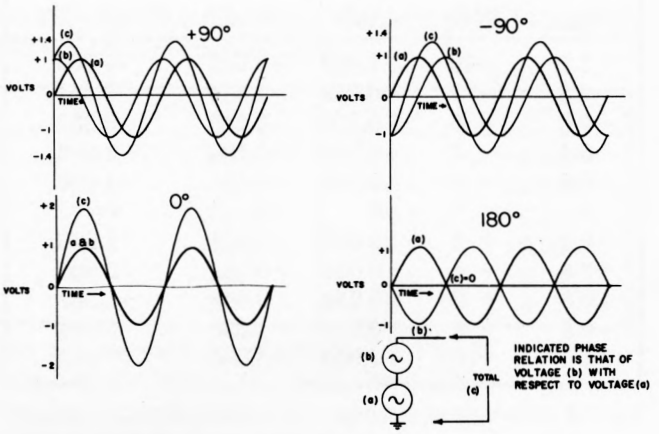


Figure 43. The Addition of Two Sinusoidal Voltages.

When both voltages are sinusoidal, and the frequencies are identical, and the voltages are exactly in phase, the two reach their peaks at the same instant and at that time they add directly (e.g. 1.0 + 1.0 = 2.0) so the peak voltage of the total is the sum of the two components (shown as the 0° condition).

When there is a 90° phase difference between the two, the total reaches its maximum at a time when each of the components is at 0.7 of peak, so the peak voltage of the total is reduced to 0.7 of the sum of the peak voltages of the components [e.g. +0.7 + 0.7 = 1.4 (the +90° and −90° conditions)]. When the two voltages have opposite phase (180° out of phase), they are equal and opposite at all times, and the total is 0 (the 180° condition).

Next consider two sinusoidal voltages having slightly different frequencies. Figures 44(a and b) illustrate the waveforms of two particular voltages. Each is sinusoidal, with a peak amplitude of 2 volts. One has a frequency of 5 MHz, a time-per-cycle of 1/5 microsecond; the other has a fre-

quency of 6 MHz, and a time-per-cycle of 1/6 μsec. Thus, the former completes 5 cycles in a microsecond while the latter is completing 6 cycles.

Superimposing the two waveforms on each other [Fig. 44(c)] shows clearly a highly significant fact: the phase relation between them is changing constantly. Initially they are in phase (both at positive peak). After ¼ microsecond the 5-MHz voltage has gone through 1¼ cycles and is 0, going negative, while the other has gone through three half-cycles and is at its negative peak. They differ in phase by 90°. After ½ microsecond the 5-MHz one is at its negative peak, while the 6-MHz one is at its positive peak, and they are 180° out of phase. As time goes on, they go through all possible phase relations, coming back to the "in phase" condition once each microsecond. It is true in general that when signals have different frequencies their phase relation changes constantly.

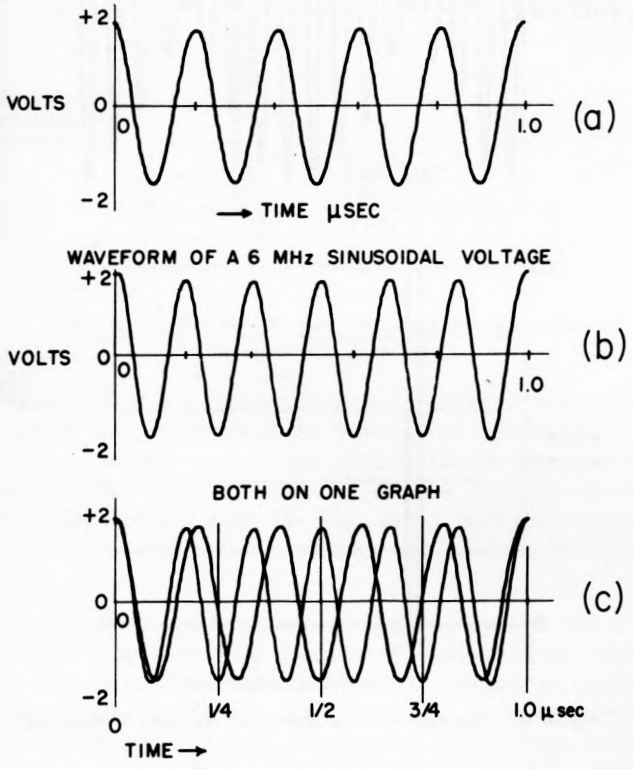


Figure 44. Waveform of a 5 MHz and of a 6 MHz Sinusoidal Voltage.

Now what happens when these two voltages are added? The total follows the principles illustrated in Fig. 43. When the two components are in phase, they add to produce a maximum peak voltage, when they are 180° out they cancel, and in between the peak amplitude changes from one condition toward the other. The resulting waveform is illustrated in Fig. 45(a), showing the two component voltages and the total superimposed, and Fig. 45(b), showing the total alone. The total voltage reaches a 4-volt maximum peak initially when the two are in phase, the

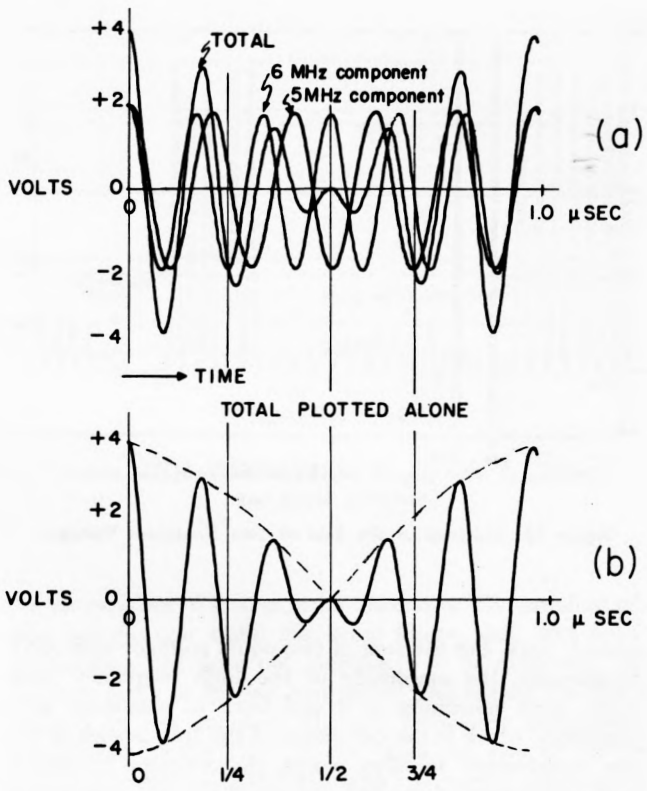


Figure 45. The Sum of Two Equal 5 MHz and 6 MHz Voltages.

peaks reduce on successive cycles reaching 0 after ½ microsecond when the two components are 180° out of phase, and building up again to a 4-volt maximum peak after one microsecond when they come back in phase again.

Care must be exercised in using the term "peak" in reference to a varying voltage with a waveform like this. The basic meaning of the word "peak" for any periodic waveform is "the highest voltage reached at any point in the cycle." In this sense the peak voltage of this waveform is 4 volts, and it is reached once each microsecond. In another sense this voltage reaches a 4-volt positive peak at 0 on the time scale, then goes to a slightly lower (−3.5 volt) negative peak, then to a 3-volt positive peak and so on. If two lines are drawn through these peaks, as illustrated in Fig. 45(b), they are said to outline the "envelope" of the waveform.

The two kinds of peak voltage can be distinguished by calling the former the "peak of the envelope" and the latter the "high-frequency" peak. In reference to Fig. 45(b), it would be correct to say that the envelope peak voltage is four volts, and the envelope frequency is 1 MHz. It could be said further that the high frequency peak voltage varies from a maximum of 4 volts down to a minimum of zero.

This sum of two particular sinusoidal voltages demonstrates several characteristics common to all sums of two such voltages without regard to their frequencies. One characteristic is the variation in the amplitude of the high fre-

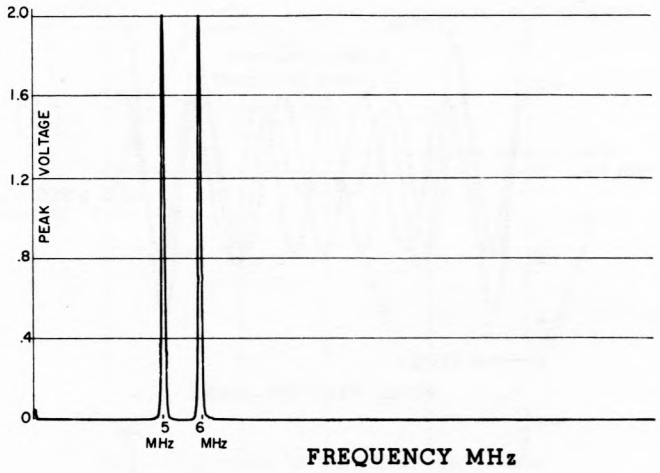


Figure 46. Spectrum of the Sum of Two Sinusoidal Voltages.

quency peak. For the sum of two equal voltages with ANY frequencies, the amplitude of the high frequency peak varies from maximum to 0 and back to maximum at a frequency which is the difference of the frequencies of the two components. In other words, the envelope frequency is the difference of the frequencies of the two component voltages. In this example the envelope frequency is 1 MHz, the difference between 6 MHz and 5 MHz.

Next consider the spectrum diagram of the voltage whose waveform is illustrated in Fig. 45(b). This is shown in Fig. 46. It shows two components, one at 5 MHz and one at 6 MHz, each having an amplitude of two volts. There is no component at 1 MHz, nor at any frequencies other than 5 and 6 MHz. This should not be surprising since this voltage is initially defined as the sum of two, and only two, sinusoidal components.

In discussing AC voltage it was clear that saying "the DC component is zero," does not mean "there is no voltage present." Any AC voltage averages zero, and thus has no DC component, when the area above zero and that below are equal over one cycle (see Fig. 31). Similar reasoning applied to the waveform of Fig. 45(b) shows how it can be true that "the amplitude of the high frequency peaks varies at a 1-MHz rate" and yet "there is no 1-MHz component present." Since the peaks above zero have higher amplitudes at the same time as those below zero and lower amplitudes at the same time, they cancel each other and there is no average variation at the 1-MHz frequency.

The statement "this voltage has components only at 5 MHz and 6 MHz" means that the waveform shown is duplicated precisely by adding together equal 5 and 6-MHz sinusoidal voltages. As long as this waveform is duplicated WITHOUT ANY DISTORTION no additional components are necessary to reproduce it. A general principle relating to amplifiers can be stated:

Only when an amplifier distorts does the output signal contain components at frequencies differing from the frequencies of the input signal components.

Two Sinusoidal Input Voltages with Second Order Distortion

It has been shown that, when two sinusoidal components are fed into a distortionless amplifier, the output contains only the two original components, or in other words, the waveform of the output is the same as that of the input.

Fig. 47 illustrates again the waveform and spectrum in this case, showing how the high-frequency peak voltage varies at the difference frequency (f_2-f_1) as the phase relation between the components changes.

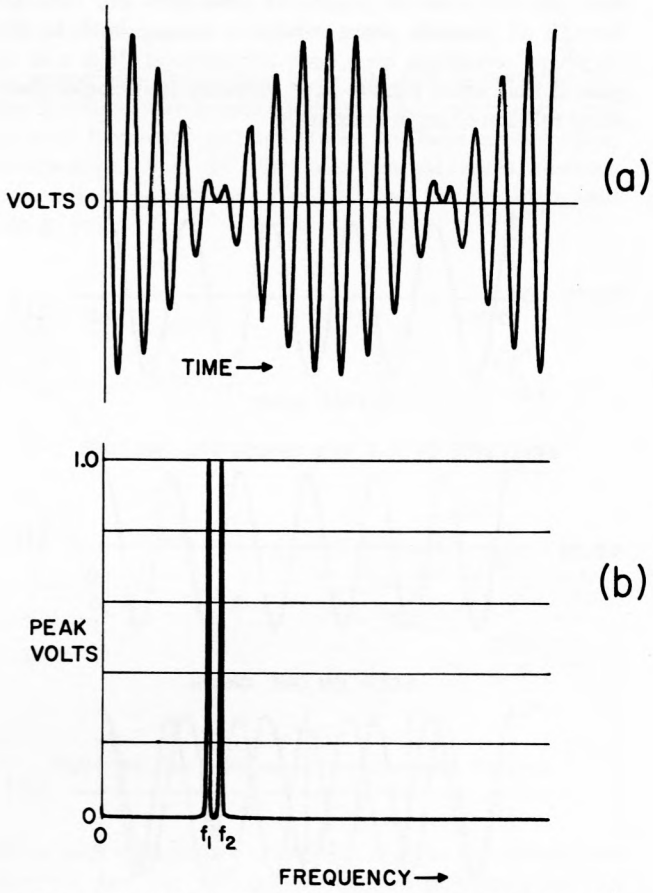


Figure 47. The Sum of Two Sinusoidal Voltages Undistorted.

Next consider what happens when two sinusoidal voltages are added and introduced into an amplifier with second order distortion. Fig. 48(a) shows a plot of the resulting distorted waveform.

Since the output waveform has a decidedly different shape from that of the input [compare Fig. 48(a) and Fig. 47(a)], it is clear that there must be components at frequencies other than the two original ones. Fig. 48(b) illustrates the five new frequency components that are added to the output voltage by second order distortion. Since the positive peaks in the output are stretched, and the negative peaks flattened, there is a general shift in level in the positive direction, and there must be a corresponding positive DC component. Since the peaks above 0 no longer average out with the peaks below 0, there is also a component at the difference frequency (f_2-f_1). For a similar

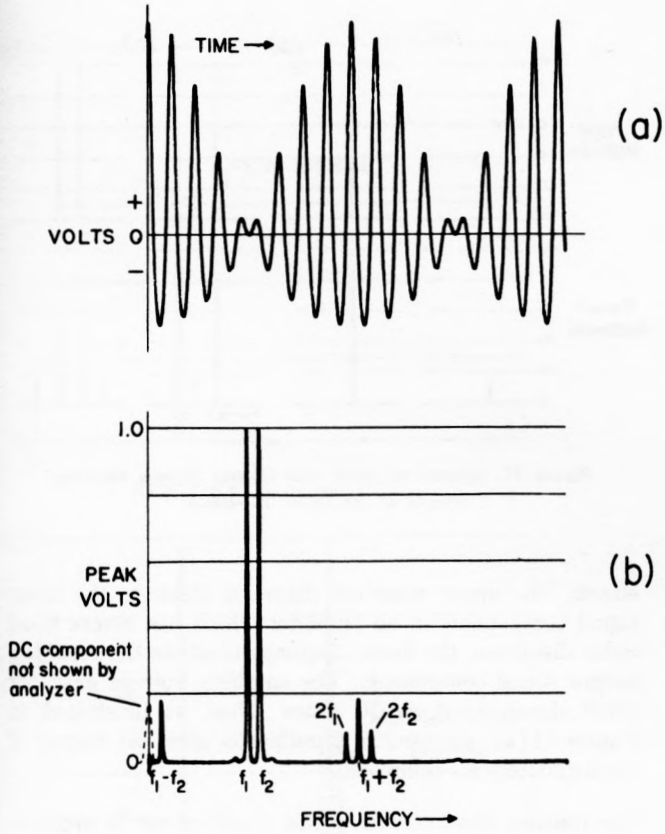


Figure 48. The Sum of Two Sinusoidal Voltages with Second Order Distortion.

reason, there is a component at a frequency which is the sum of the frequencies of the two original signals (f_1+f_2). And, of course, each of the original signals generates a second harmonic (at $2f_1$ and $2f_2$). Thus the spectrum of the output signal looks like Fig. 48(b) with components at the two original frequencies as well as at the five new ones.

An important conclusion can be drawn from this one example: Whenever more than one sinusoidal voltage (that is when more than one signal) is introduced into an amplifier which has second order distortion, the output will include signals at certain frequencies differing from those of the input signals. There will be a DC component, a shift in the average collector current of the distorting stage (which does not show up in the output when AC coupling is used), a component at a frequency which is the difference of the two original frequencies, a component at a frequency which is the sum of the original frequencies, and components at twice each of the original frequencies.

When the original signals are modulated with picture information, each of these spurious signals will carry the modulation of both of the original signals from which it comes.

Why Second Order Distortion Is Unimportant in Present CATV Systems

Anyone who has worked with CATV equipment in the past recognizes the fact that very little attention has been paid

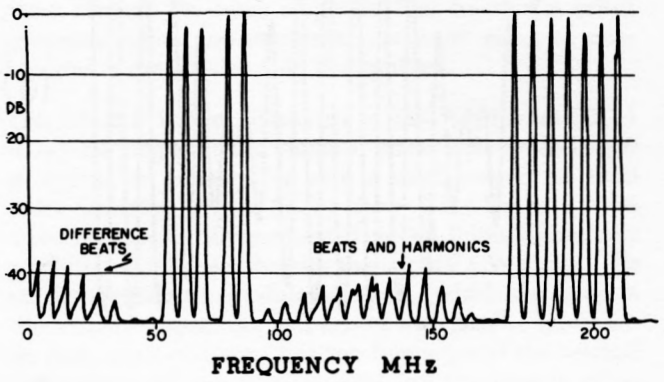


Figure 49. Spectrum of 12 CW Signals with Appreciable 2nd Order Distortion.

to the problem of second order distortion. The usual amplifier specification states the noise figure, gain and cross-modulation but does not mention sum or difference frequency beats or second harmonics. The reason for this is related to the standard channel frequency assignments established by the FCC. If one takes any pair of picture carrier frequencies in the standard 12-channel assignments, their sum or difference does not fall in any of those channels. Similarly, with one minor exception (channel 6 sound carrier), the second harmonics of all low band carriers fall between the two bands. Figure 49 shows the spectrum obtained when 12 CW signals on the normal picture carrier frequencies were introduced into a CATV amplifier at levels somewhat higher than normal operating level.

This shows how the spurious signals resulting from second order distortion fall below and between the bands, but not within the channel limits. Since this is true, second order distortion has no bad effects on an amplifier carrying up to twelve standard TV channels, and normally is not considered in this case.

Two Sinusoidal Input Voltages with Third Order Distortion

Figure 50(a) illustrates the appearance of the output voltage of an amplifier having third order distortion when the sum of two sinusoidal voltages [similar to that shown in Figure 47(a)] is introduced into the input. The flattening of the larger vertical peaks is clearly evident. A spectrum diagram showing the frequency components in the output is shown in Figure 50(b). In addition to the two original sinusoidal components (at f_1 and f_2) spurious signals occur at the following frequencies:

$2f_1-f_2$ This falls below f_1 at a spacing corresponding to the frequency difference between f_1 and f_2.

$2f_2-f_1$ This falls above f_2 at a spacing corresponding to the frequency difference between f_1 and f_2.

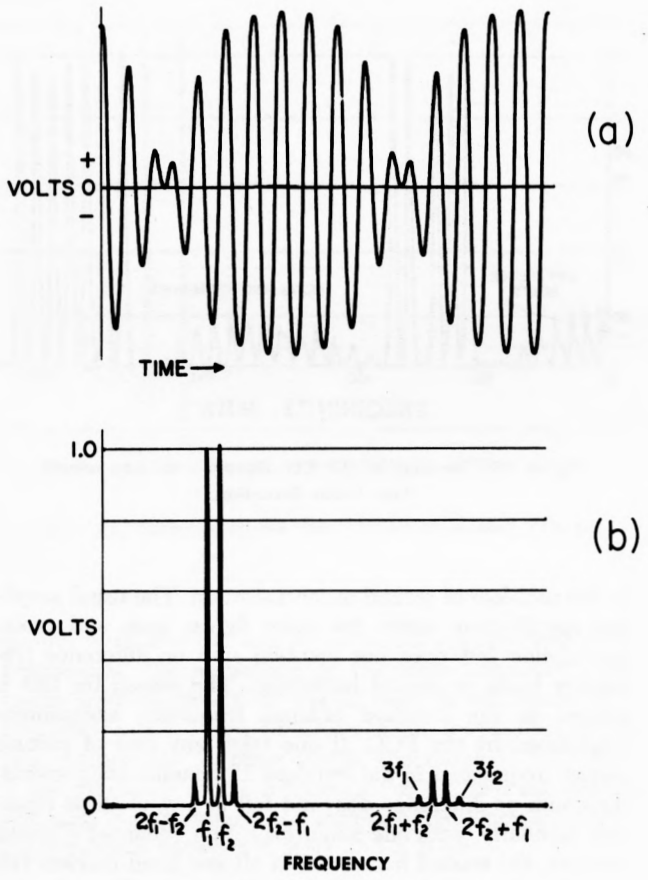


Figure 50. The Sum of Two Sinusoidal Voltages with Third Order Distortion.

$3f_1$ and $3f_2$ — These are the third harmonics and the spacing between is three times the spacing between f_1 and f_2.

$2f_1+f_2$ — This falls above $3f_1$ at a spacing corresponding to the frequency difference between f_1 and f_2.

$2f_2+f_1$ — This falls below $3f_2$ at a spacing corresponding to the same difference.

Cross-Modulation and Compression

The spurious signals generated by third order distortion can give trouble in any multi-channel system since it is possible for them to fall within some of the channels. In present CATV systems they do not generally cause as much trouble as another effect of third order distortion, "cross-modulation." This is one of the two important aspects of third order distortion which do not result in components at new frequencies. (The other being "compression"). Each of these effects represents a change in gain at the channel frequencies rather than the generation of new frequency components. Figure 51 illustrates these

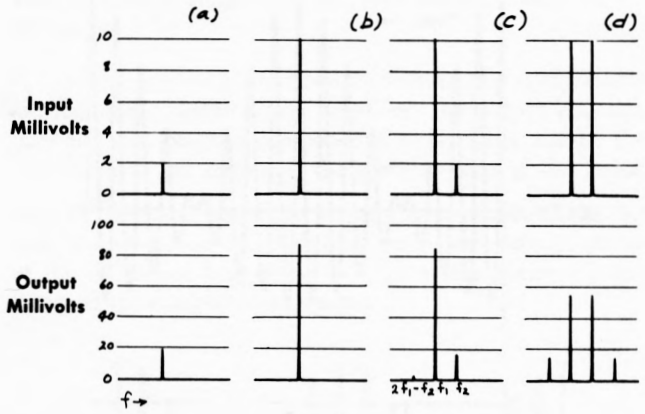


Figure 51. Spectra of Input and Output Signals Showing Effects of 3d Order Distortion.

effects. The upper spectrum diagrams illustrate the input signal components in an amplifier which has severe third order distortion, the lower diagrams illustrate the resulting output signal components. The amplifier voltage gain, for small signal input, is 10 times. Thus, as illustrated in Figure 51(a), an input of 2 millivolts gives an output of approximately 20 millivolts.

The transfer characteristic of this amplifier can be approximated by an equation where a "cubed" term is subtracted from a "linear" term, with a shape resembling Fig. 39(c). With such a characteristic the effective gain decreases as the input signal amplitude increases. Thus, as shown in Figure 51(b), increasing the input signal of this amplifier to 10 millivolts results in an output of 90 millivolts, rather than 100 millivolts which would be obtained if the gain were not reduced by the effects of third order distortion. This effect, the reduction in gain at a single frequency as the signal amplitude increases, is called *compression* and results in the distortion of the modulation envelope on any modulated signal going through such an amplifier. When this effect occurs in an amplifier carrying a single TV-modulated signal, it results in a flattening of the sync peaks which is called "sync compression."

Figure 51(c) shows what happens when a signal is introduced at low level on another frequency. Several effects can be seen: The output level on the new frequency is somewhat below the 20-millivolt point it would reach if the strong signal were not present; the strong signal output is slightly reduced by the presence of the new signal [compare with (b)], and a spurious component at $2f_1-f_2$ can be seen.

As shown in Figure 51(d), increasing the second input signal to full amplitude results in a further reduction in gain so that both output signals at the original frequencies are below 60 millivolts and the spurious signals increase in amplitude. The most significant effect here is that the gain on each channel is reduced not only by an increase in level on that channel but also by the increase in level on the other channel. This results in a transfer of any varia-

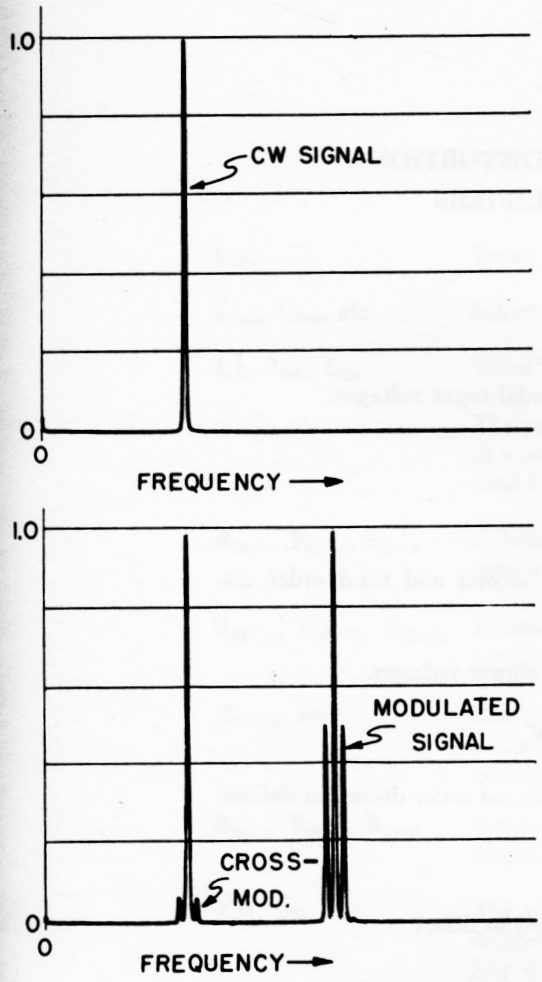


Figure 52. Spectrum Showing Cross-Mod.

tion, or modulation, on one carrier to any other carriers going through the same amplifier. This transfer is called cross-modulation and represents the worst effect of non-linearity in present-day CATV amplifiers.

This effect is further illustrated in Fig. 52. Figure 52(a) shows the output signal obtained when a sinusoidal input is applied to an amplifier with a small amount of third order distortion. Figure 52(b) shows what happens when a second signal, fully modulated, is fed through the same amplifier, simultaneously with the original CW signal. The output includes the modulated signal (which shows up in the frequency spectrum as a carrier with smaller sidebands on each side), the output at the frequency of the original CW signal, and two spurious sideband components which show up adjacent to the CW signal frequency as a result of third order distortion. It is clear how this distortion results in a transfer of modulation from one signal to the other.

Conclusion

This chapter has attempted to describe all of the effects which result from the simplest kinds of non-linearity, second order and third order distortion, in amplifiers of the type used for CATV systems. It has shown that second order effects are generally unimportant with present-day frequency assignments and that, of all the third order effects, cross-modulation is the most important, representing the factor which limits the output level at which the amplifiers in these systems may be operated without degrading the picture quality at the receivers served by the system.

CHAPTER V

A MATHEMATICAL ANALYSIS OF DISTORTION AS IT OCCURS IN CATV AMPLIFIERS

LIST OF SYMBOLS

(in the order of their use)

A, B, C	Amplitudes of each of three sinusoidal input voltages.
f_a, f_b, f_c	Corresponding frequencies.
a, b, c	$a = 2\pi f_a t$, $b = 2\pi f_b t$, $c = 2\pi f_c t$.
k_1, k_2, k_3	Constants characterizing the first, second and third order distortion of the amplifier.
e_{in}, e_{out}	The total instantaneous input and output voltages.
L_a, L_b, L_c	First Order output levels, in dBmV.
K_2	A decibel constant characterizing second order distortion defined by: $K_2 = 20 \log_{10} \frac{\frac{k_2}{\sqrt{2}}}{\left(\frac{k_1}{\sqrt{2}}\right)^2}$ Expressed in dBmV. K_2 is always a negative number since $k_2 << k_1^2$.
L_{ab}, L_{bc}, L_{ac}	Sum or difference beat level, in dBmV.
L_{2a}, L_{2b}, L_{2c}	Second harmonic levels, in dBmV.
K_3	A decibel constant characterizing third order distortion, defined by: $K_3 = 20 \log_{10} \frac{3}{2} \frac{\frac{k_3}{\sqrt{2}}}{\left(\frac{k_1}{\sqrt{2}}\right)^3}$ Expressed in dBmV. K_3 is always a negative number since $k_3 << k_1^3$.

L_{abc}	Triple beat levels, in dBmV.
L_{2ab}, L_{2ac}, etc.	Intermodulation Component levels, in dBmV.
L_{3a}, L_{3b}, L_{3c}	Third Harmonic levels, in dBmV.
$R_{ab/a}$, etc.	The relative level of the sum or difference beat between signals at a and b referred to the level of a, in dB. Similar symbols are used for other pairs of signals and other reference signals.
$R_{2a/a}$, $R_{2b/b}$, $R_{2c/c}$	Relative level of second harmonic, referred in each case to the output level at the fundamental frequency, in dB.
$R_{abc/a}$, $R_{abc/b}$, $R_{abc/c}$	Relative level of the triple beat, referred to each of the three output signals, in dB.
$R_{2ab/a}$, etc.	Relative level of each of the Intermodulation components referred to the indicated output. In this example the relative level of the component at $2f_a \pm f_b$ with reference to the level at f_a, in dB.
$R_{3a/a}$, $R_{3b/b}$, $R_{3c/c}$	Relative level of each third harmonic component, referred to the output level at the fundamental frequency, in dB.
XM, xm	XM is the NCTA standard cross-modulation ratio expressed in decibel form, xm is the same ratio in voltage form. $XM = 20 \log_{10} xm$.
M, m	m is the conventional modulation factor: $m = \frac{e_{max} - e_{min}}{e_{max} + e_{min}}$ (100 m = % modulation). M is the modulation factor in decibel form: $M = 20 \log_{10} m$.
n	n is the total number of input signals applied to an amplifier, including the test signal.
$e_{a(D)}$	This is the amplitude of the output voltage at f_a including the effects of third order distortion. (As contrasted with the undistorted output = k_1A.)
r_{abc}	The voltage ratio of the triple beat output component amplitude to the first order output at f_a. When $A = B = C$, $r_{abc} = 3/2 \frac{k_3}{k_1} A^2$. $R_{abc/a} = 20 \log_{10} r_{abc}$.

A SUMMARY OF THE DECIBEL EXPRESSIONS

OUTPUT LEVELS EXPRESSED IN dBmV

First Order Output Component Levels:

$$L_a = 20 \log_{10} \left(\frac{k_1 A}{\sqrt{2}} \right), \text{ at } f_a$$

$$L_b = 20 \log_{10} \left(\frac{k_1 B}{\sqrt{2}} \right), \text{ at } f_b$$

$$L_c = 20 \log_{10} \left(\frac{k_1 C}{\sqrt{2}} \right), \text{ at } f_c$$

Second Order Distortion Component Levels:

Sum and Difference Beats:

$$L_{ab} = K_2 + L_a + L_b \text{ (at } f_a \pm f_b)$$
$$L_{bc} = K_2 + L_b + L_c \text{ (at } f_b \pm f_c)$$
$$L_{ac} = K_2 + L_a + L_c \text{ (at } f_a \pm f_c)$$

Second Harmonics:

$$L_{2a} = K_2 + 2L_a - 6, \text{ at } 2f_a$$
$$L_{2b} = K_2 + 2L_b - 6, \text{ at } 2f_b$$
$$L_{2c} = K_2 + 2L_c - 6, \text{ at } 2f_c$$

Third Order Distortion Components:

Triple Beat Component Levels:

$$L_{abc} = K_3 + L_a + L_b + L_c \text{ (at } f_a \pm f_b \pm f_c)$$

Intermodulation Component Levels:

$$L_{2ab} = K_3 + 2L_a + L_b - 6\text{dB (at } 2f_a \pm f_b)$$
$$L_{2ac} = K_3 + 2L_a + L_c - 6\text{dB (at } 2f_a \pm f_c)$$
$$L_{2ba} = K_3 + 2L_b + L_a - 6\text{dB (at } 2f_b \pm f_a)$$
$$L_{2bc} = K_3 + 2L_b + L_c - 6\text{dB (at } 2f_b \pm f_c)$$
$$L_{2ca} = K_3 + 2L_c + L_a - 6\text{dB (at } 2f_c \pm f_a)$$
$$L_{2cb} = K_3 + 2L_c + L_b - 6\text{db (at } 2f_c \pm f_b)$$

Third Harmonic Component Levels:

$$L_{3a} = K_3 + 3L_a - 15.5 \text{ (at } 3f_a)$$
$$L_{3b} = K_3 + 3L_b - 15.5 \text{ (at } 3f_b)$$
$$L_{3c} = K_3 + 3L_c - 15.5 \text{ (at } 3f_c)$$

RELATIVE DISTORTION EXPRESSED IN DECIBELS

Relative Second Order Distortion:

Relative Sum or Difference Beat

$$R_{ab/a} = K_2 + L_b \text{ (at } f_a \pm f_b)$$
$$R_{bc/b} = K_2 + L_c \text{ (at } f_b \pm f_c)$$
$$R_{ac/a} = K_2 + L_c \text{ (at } f_a \pm f_c)$$
$$R_{ab/b} = K_2 + L_a \text{ (at } f_a \pm f_b)$$
$$R_{bc/c} = K_2 + L_b \text{ (at } f_b \pm f_c)$$
$$R_{ac/c} = K_2 + L_a \text{ (at } f_a \pm f_c)$$

Relative Second Harmonic:

$$R_{2a/a} = K_2 + L_a - 6 \text{ (at } 2f_a)$$
$$R_{2b/b} = K_2 + L_b - 6 \text{ (at } 2f_b)$$
$$R_{2c/c} = K_2 + L_c - 6 \text{ (at } 2f_c)$$

Relative Third Order Distortion:

Relative Triple Beat:

$$R_{abc/a} = K_3 + L_b + L_c \text{ (at } f_a \pm f_b \pm f_c)$$
$$R_{abc/b} = K_3 + L_a + L_c \text{ (at } f_a \pm f_b \pm f_c)$$
$$R_{abc/c} = K_3 + L_a + L_b \text{ (at } f_a \pm f_b \pm f_c)$$

Relative Intermodulation:

$$R_{2ab/a} = K_3 + L_a + L_b - 6dB \text{ (at } 2f_a \pm f_b)$$
$$R_{2ab/b} = K_3 + 2L_a - 6dB \text{ (at } 2f_a \pm f_b)$$
$$R_{2ac/a} = K_3 + L_a + L_c - 6dB \text{ (at } 2f_a \pm f_c)$$
$$R_{2ac/c} = K_3 + 2L_a - 6dB \text{ (at } 2f_a \pm f_c)$$
$$R_{2bc/b} = K_3 + L_b + L_c - 6dB \text{ (at } 2f_b \pm f_c)$$
$$R_{2bc/c} = K_3 + 2L_b - 6dB \text{ (at } 2f_b \pm f_c)$$
$$R_{2ba/a} = K_3 + 2L_b - 6dB \text{ (at } 2f_b \pm f_a)$$
$$R_{2ba/b} = K_3 + L_a + L_b - 6dB \text{ (at } 2f_b \pm f_a)$$
$$R_{2ca/a} = K_3 + 2L_c - 6dB \text{ (at } 2f_c \pm f_a)$$
$$R_{2ca/c} = K_3 + L_c + L_a - 6dB \text{ (at } 2f_c \pm f_a)$$
$$R_{2cb/b} = K_3 + 2L_c - 6dB \text{ (at } 2f_c \pm f_b)$$
$$R_{2cb/c} = K_3 + L_c + L_b - 6dB \text{ (at } 2f_c \pm f_b)$$

Relative Third Harmonic:

$$R_{3a/a} = K_3 + 2L_a - 15.5dB \text{ (at } 3f_a)$$
$$R_{3b/b} = K_3 + 2L_b - 15.5dB \text{ (at } 3f_b)$$
$$R_{3c/c} = K_3 + 2L_c - 15.5dB \text{ (at } 3f_c)$$

NCTA Cross-Modulation

$$XM = K_3 + 2L + 20 \log_{10} (n - 1)$$

Cross-Modulation in Terms of "M"

$$M = K_3 + 2L + 20 \log_{10} (n - 1) - 6dB$$

INTRODUCTION:

The preceding chapter "The Fundamentals of Distortion in CATV Amplifiers" develops, chiefly from a graphical standpoint, the general nature of distortion as it occurs in CATV amplifiers. It illustrates the spectra of spurious signals generated by second and third order curvature in the transfer characteristic, and describes the compression and cross-modulation effects resulting from third order curvature. In this chapter the quantitive relationships between the various distortion products will be developed mathematically, and a consistent way of expressing them in the convenient decibel "language" of CATV will be shown.

It must be borne in mind in considering what follows that some of the basic assumptions necessary to permit easy mathematical development are not completely justified in reality. For example, the assumption that the gain and distortion coefficients (k_1, k_2, and k_3) are constant for all input signal frequencies is distinctly at variance with the measured performance of practical amplifiers. These discrepancies, while very significant, do not nullify the usefulness of the relationships developed. However, extreme care must be exercised when drawing conclusions concerning real amplifiers from the mathematical considerations.

RESULTS OF THE BASIC MATHEMATICAL DEVELOPMENT:

Assume an amplifier with 75-ohm input and output impedances and with sinusoidal input voltages at each of three frequencies:

$$e_{in} = A \cos a + B \cos b + C \cos c$$

(Note that A cos a and A sin a are both *sinusoidal* voltages. Their waveforms are identical except for a 90° phase difference. The cosine form is used throughout this analysis because it results in simpler expressions.)

A, B and C are the amplitudes of each voltage respectively, measured in millivolts.

Also: $a = 2\pi f_a t$, $b = 2\pi f_b t$ and $c = 2\pi f_c t$; $a > b > c$

Assume further that the transfer characteristic of the amplifier can be accurately represented at all frequencies by a power series containing three terms:

$$e_{out} = k_1 e_{in} + k_2 e_{in}^2 + k_3 e_{in}^3$$

e_{in} is the instantaneous input voltage as described above, k_1, k_2 and k_3 are complex numbers describing the gain, phase shift and distortion properties of the amplifier. Although, in a real amplifier, *any* phase angle may be associated with each of these constants, in this example the phase angle for k_1 and k_2 will be assumed to be 0°, and that for k_3 either 0° (indicated by a + sign) or 180° (indicated by a − sign).

With these conditions the output will contain the following sinusoidal components (see Appendix I, p. 105 for derivation):

First Order Components:

Components identical with the input signals except with increased amplitude.	$k_1 e_{in} =$ $+ k_1 A \cos a$ $+ k_1 B \cos b$ $+ k_1 C \cos c$	*Three* First Order Output Components *These represent the result of linear amplification. k_1 is the small-signal voltage gain of the amplifier.*

Second Order Distortion Components:

These represent a shift in average level.	$k_2 e_{in}^2 =$ $+ \frac{k_2 A^2}{2}$ $+ \frac{k_2 B^2}{2}$ $+ \frac{k_2 C^2}{2}$	*Three* DC Components *due to second order distortion.*
Components at frequencies which are combinations of input signal frequencies.	$+ k_2 AB \cos(a \pm b)$ $+ k_2 AC \cos(a \pm c)$ $+ k_2 BC \cos(b \pm c)$	*Six* Sum and Difference Beat Components.
Components at twice the input signal frequencies.	$+ \frac{k_2 A^2}{2} \cos 2a$ $+ \frac{k_2 B^2}{2} \cos 2b$ $+ \frac{k_2 C^2}{2} \cos 2c$	*Three* Second Harmonic Components.

Third Order Distortion Components:

The first three groups of Third order components contain components at frequencies differing from the frequencies of the input signals.

$k_3 e_{in}^3 =$

Components at three times each input frequency.	$+ 1/4k_3A^3 \cos 3a$ $+ 1/4k_3B^3 \cos 3b$ $+ 1/4k_3C^3 \cos 3c$	*Three* Third Harmonic Components.
Components at frequencies which are combinations of input signal frequencies.	$+ 3/4k_3A^2B \cos(2a \pm b)$ $+ 3/4k_3A^2C \cos(2a \pm c)$ $+ 3/4k_3B^2A \cos(2b \pm a)$ $+ 3/4k_3B^2C \cos(2b \pm c)$ $+ 3/4k_3C^2A \cos(2c \pm a)$ $+ 3/4k_3C^2B \cos(2c \pm b)$	*Twelve* Intermodulation (*2a ± b beat*) Components, and
	$+ 3/2k_3ABC \cos(a \pm b \pm c)$	*Four* Triple (abc) Beat Components.

The last two groups contain components at the frequencies of the input signals. When k_3 is positive, these components *add* to the first order output causing an increase in gain which is called *expansion*. When k_3 is negative, they *subtract* causing a decrease in gain which is called *compression*.

Components at the frequency of each input signal with amplitude determined by the input voltage of that signal cubed.	$+ 3/4k_3A^3 \cos a$ $+ 3/4k_3B^3 \cos b$ $+ 3/4k_3C^3 \cos c$	*Three components causing* Self-compression *when k_3 is negative,* Self-expansion *when k_3 is positive.*
Components at the frequency of each input signal with amplitude determined by the input voltage at that frequency, and the square of the input voltage at one other frequency.	$+ 3/2k_3AB^2 \cos a$ $+ 3/2k_3AC^2 \cos a$ $+ 3/2k_3BA^2 \cos b$ $+ 3/2k_3BC^2 \cos b$ $+ 3/2k_3CA^2 \cos c$ $+ 3/2k_3CB^2 \cos c$	*Six components causing* Cross-compression when *k_3 is negative,* Cross-expansion *when k_3 is positive.*

Self-compression and *self-expansion* describe a condition where the gain at the frequency of one of the input signals is decreased or increased as a result of increasing the input voltage of that signal.

Cross-compression and *cross-expansion* describe a condition where the gain at the frequency of one of the input signals is decreased or increased as a result of increasing the voltage of another input signal.

DECIBEL EXPRESSIONS FOR THE LEVELS OF THE OUTPUT COMPONENTS:

Decibel expressions for the output levels of each of the AC distortion components will now be formulated, and for CATV purposes they are most conveniently expressed in dBmV, the decibel ratio of the RMS voltage of the component to one millivolt RMS. The dBmV is an expression of power level, 0dBmV = −48.75 dBm.

First Order Output Component Levels:

Since the instantaneous input voltage at f_a is A cosa, where A is measured in millivolts across 75 ohms, the peak input voltage is A, and the RMS input voltage is $\frac{A}{\sqrt{2}}$, both in millivolts.

The corresponding first-order RMS output voltage is $\frac{k_1 A}{\sqrt{2}}$, obtained by multiplying the input voltage by k_1, the small signal voltage gain. Since the level in dBmV is defined as 20 $\log_{10}$ (RMS voltage in millivolts) the first order output levels, expressed in dBmV are:

$$L_a = 20 \log_{10}\left(\frac{k_1 A}{\sqrt{2}}\right), \text{ at } f_a$$

$$L_b = 20 \log_{10}\left(\frac{k_1 B}{\sqrt{2}}\right), \text{ at } f_b$$

$$L_c = 20 \log_{10}\left(\frac{k_1 C}{\sqrt{2}}\right), \text{ at } f_c$$

Second Order Distortion Component Levels:

Sum and Difference Beats:

Expressions for second order distortion levels can be obtained in the simplest form by carefully defining the constant "K_2" in the decibel equation. Its definition is accom-

plished in the following manner: The voltage expression for the amplitude of a sum beat is "k_2AB", so "$K_2 + L_a + L_b$" is chosen as a convenient decibel expression for its level. With this choice, since the level of a component is 20 $\log_{10}$ of the RMS voltage of that component:

$$K_2 + L_a + L_b = 20 \log_{10}\left(\frac{k_2AB}{\sqrt{2}}\right)$$

Substituting previously defined quantities for L_a and L_b:

$$K_2 + 20 \log_{10}\left(\frac{k_1A}{\sqrt{2}}\right) + 20 \log_{10}\left(\frac{k_1B}{\sqrt{2}}\right) = 20 \log_{10}\left(\frac{k_2AB}{\sqrt{2}}\right)$$

$$\text{so } K_2 = 20 \log_{10}\left(\frac{k_2AB}{\sqrt{2}}\right) - 20 \log_{10}\left(\frac{k_1A}{\sqrt{2}}\right) - 20 \log_{10}\left(\frac{k_1B}{\sqrt{2}}\right)$$

$$= 20 \log_{10}\left[\frac{k_2AB}{\sqrt{2}} \cdot \frac{\sqrt{2}}{k_1A} \cdot \frac{\sqrt{2}}{k_1B}\right]$$

$$\text{or} \quad K_2 = 20 \log_{10} \frac{\frac{k_2}{\sqrt{2}}}{\left(\frac{k_1}{\sqrt{2}}\right)^2}$$

With this definition of K_2 Sum and Difference beat levels in dBmV are expressed as follows:

$$L_{ab} = K_2 + L_a + L_b \text{ (at } f_a \pm f_b)$$
$$L_{bc} = K_2 + L_b + L_c \text{ (at } f_b \pm f_c)$$
$$L_{ac} = K_2 + L_a + L_c \text{ (at } f_a \pm f_c)$$

Second Harmonics:

The amplitude of the second harmonic output at $2f_a$ is $\frac{k_2A^2}{2}$.

The corresponding RMS voltage is $\frac{k_2}{\sqrt{2}} \cdot \frac{A^2}{2}$

so the level is: $L_{2a} = 20 \log_{10}\left(\frac{k_2}{\sqrt{2}} \cdot \frac{A^2}{2}\right)$

Dividing the quantity in parentheses into convenient factors:

$$L_{2a} = 20 \log_{10}\left[\frac{\frac{k_2}{\sqrt{2}}}{\left(\frac{k_1}{\sqrt{2}}\right)^2}\right]\left(\frac{k_1}{\sqrt{2}}A\right)^2\left(\frac{1}{2}\right)$$

$$20 \log_{10}\left[\frac{\frac{k}{\sqrt{2}}}{\frac{k_1^2}{\sqrt{2}}}\right] = K_2, \; 20 \log_{10}\left(\frac{k_1}{\sqrt{2}} \cdot A\right)^2$$

$$= 2L_a, \text{ and } 20 \log_{10} \frac{1}{2} = -6\text{dB}$$

So the second harmonic output levels expressed in dBmV are:

$$L_{2a} = K_2 + 2L_a - 6, \text{ at } 2f_a$$
$$L_{2b} = K_2 + 2L_b - 6, \text{ at } 2f_b$$
$$L_{2c} - K_2 + 2L_c - 6, \text{ at } 2f_c$$

Third Order Distortion Components:

First, a quantity "K_3" is defined to provide a simple expression for each Triple Beat component:

$$\text{Assume: } K_3 + L_a + L_b + L_c = 20 \log_{10}\left(\frac{3/2\, k_3ABC}{\sqrt{2}}\right)$$

$$K_3 = 20 \log_{10}\left(\frac{3}{2} \cdot \frac{k_3}{\sqrt{2}} \cdot ABC\right) - 20 \log_{10} \frac{k_1}{\sqrt{2}} A$$
$$- 20 \log_{10} \frac{k_1}{\sqrt{2}} B - 20 \log_{10} \frac{k_1}{\sqrt{2}} C$$

$$= 20 \log_{10}\left[\left(\frac{3}{2}\frac{k_3}{\sqrt{2}} ABC\right)\left(\frac{1}{\frac{k_1}{\sqrt{2}} A}\right)\left(\frac{1}{\frac{k_1}{\sqrt{2}} B}\right)\left(\frac{1}{\frac{k_1}{\sqrt{2}} C}\right)\right]$$

$$\text{or} \quad K_3 = 20 \log_{10} 3/2 \frac{\frac{k_3}{\sqrt{2}}}{\left(\frac{k_1}{\sqrt{2}}\right)^3}$$

With this definition of K_3, the triple beat levels are given by:

Triple Beat Component Levels:

$$L_{abc} = K_3 + L_a + L_b + L_c \text{ (at } f_a \pm f_b \pm f_c)$$

Intermodulation Component Levels:

Since the coefficient of each of the Intermodulation Components is 3/4, which is 1/2 of the coefficient of the Triple Beat components, 20 $\log_{10}$ 1/2 = −6 dB is added to obtain the decibel expressions for the intermodulation components:

$$L_{2ab} = K_3 + 2L_a + L_b - 6\text{dB (at } 2f_a \pm f_b)$$
$$L_{2ac} = K_3 + 2L_a + L_c - 6\text{dB (at } 2f_a \pm f_c)$$
$$L_{2ba} = K_3 + 2L_b + L_a - 6\text{dB (at } 2f_b \pm f_a)$$
$$L_{2bc} = K_3 + 2L_b + L_c - 6\text{dB (at } 2f_b \pm f_c)$$
$$L_{2ca} = K_3 + 2L_c + L_a - 6\text{dB (at } 2f_c \pm f_a)$$
$$L_{2cb} = K_3 + 2L_c + L_b - 6\text{db (at } 2f_c \pm f_b)$$

Third Harmonic Component Levels:

The coefficient of each Third Harmonic Component is 1/4, which is $\frac{1}{6}$ the coefficient of each Triple Beat component.

To express this in dB, $20 \log_{10} \frac{1}{6} = -15.5\text{dB}$ is added to each Third Harmonic Component level:

$$L_{3a} = K_3 + 3L_a - 15.5 \text{ (at } 3f_a)$$
$$L_{3b} = K_3 + 3L_b - 15.5 \text{ (at } 3f_b)$$
$$L_{3c} = K_3 + 3L_c - 15.5 \text{ (at } 3f_c)$$

Expansion/compression

It is pointless to express the levels of the expansion/compression terms in dBmV. They are considered later in this chapter.

RELATIVE DISTORTION EXPRESSED IN DECIBELS:

In the measurement and specification of distortion, it is common practice to deal with *relative* distortion, i.e. to relate the amplitude of the distortion component to the amplitude of the undistorted output component. Harmonic distortion, for example, is commonly described in terms of "percent harmonic" which is 100 times the ratio of the harmonic component amplitude to the fundamental component amplitude.

When the levels of the undistorted (first order) components and of the various distortion components are expressed in decibel terms it is easy to arrive at a statement of relative distortion. The relation, in decibels, between any given distortion component, expressed in dBmV, and a given first order output, also in dBmV, is simply the difference (in dB) between the two levels.

Relative Second Order Distortion:

Relative Sum or Difference Beat

The level of a particular sum beat component is, for example:

$$L_{ab} = K_2 + L_a + L_b \text{ (at } f_a + f_b)$$

and the level of the first order output at f_a is L_a, so the *relative* sum beat is the difference of the two levels:

$$R_{ab/a} = L_{ab} - L_a = K_2 + L_a + L_b - L_a$$
$$= K_2 + L_b$$

Where "$R_{ab/a}$" is read "The sum beat (at $f_a + f_b$) in dB relative to the output level at f_a." L_a, L_b and K_2 are expressed in dBmV. $R_{ab/a}$ is expressed in dB. So for the twelve possible combinations of sum and difference beat components related to the three first order output levels:

$$R_{ab/a} = K_2 + L_b \text{ (at } f_a \pm f_c)$$
$$R_{bc/b} = K_2 + L_c \text{ (at } f_b \pm f_c)$$
$$R_{ac/a} = K_2 + L_c \text{ (at } f_a \pm f_c)$$
$$R_{ab/b} = K_2 + L_a \text{ (at } f_a \pm f_b)$$
$$R_{bc/c} = K_2 + L_b \text{ (at } f_b \pm f_c)$$
$$R_{ac/c} = K_2 + L_a \text{ (at } f_a \pm f_c)$$

Relative Second Harmonic:

Similarly the second harmonic of the output at f_a relative to the fundamental is given by:

$$R_{2a/a} = L_{2a} - L_a = K_2 + 2L_a - 6 - L_a$$
$$= K_2 + L_a - 6$$

so

$$R_{2a/a} = K_2 + L_a - 6 \text{ (at } 2f_a)$$
$$R_{2b/b} = K_2 + L_b - 6 \text{ (at } 2f_b)$$
$$R_{2c/c} = K_2 + L_c - 6 \text{ (at } 2f_c)$$

Relative Third Order Distortion:

Relative Triple Beat:

$$R_{abc/a} = K_3 + L_a + L_b + L_c - L_a$$

and similarly for other terms, so:

$$R_{abc/a} = K_3 + L_b + L_c \text{ (at } f_a \pm f_b \pm f_c)$$
$$R_{abc/b} = K_3 + L_a + L_c \text{ (at } f_a \pm f_b \pm f_c)$$
$$R_{abc/c} = K_3 + L_a + L_b \text{ (at } f_a \pm f_b \pm f_c)$$

Relative Intermodulation:

$$R_{2ab/a} = K_3 + L_a + L_b - 6\text{dB} \text{ (at } 2f_a \pm f_b)$$
$$R_{2ab/b} = K_3 + 2L_a - 6\text{dB} \text{ (at } 2f_a \pm f_b)$$
$$R_{2ac/a} = K_3 + L_a + L_c - 6\text{dB} \text{ (at } 2f_a \pm f_c)$$
$$R_{2ac/c} = K_3 + 2L_a - 6\text{dB} \text{ (at } 2f_a \pm f_c)$$
$$R_{2bc/b} = K_3 + L_b + L_c - 6\text{dB} \text{ (at } 2f_b \pm f_c)$$
$$R_{2bc/c} = K_3 + 2L_b - 6\text{dB} \text{ (at } 2f_b \pm f_c)$$
$$R_{2ba/a} = K_3 + 2L_b - 6\text{dB} \text{ (at } 2f_b \pm f_a)$$
$$R_{2ba/b} = K_3 + L_a + L_b - 6\text{dB} \text{ (at } 2f_b \pm f_a)$$
$$R_{2ca/a} = K_3 + 2L_c - 6\text{dB} \text{ (at } 2f_c \pm f_a)$$
$$R_{2ca/c} = K_3 + L_c + L_a - 6\text{dB} \text{ (at } 2f_c \pm f_a)$$
$$R_{2cb/b} = K_3 + 2L_c - 6\text{dB} \text{ (at } 2f_c \pm f_b)$$
$$R_{2cb/c} = K_3 + L_c + L_b - 6\text{dB} \text{ (at } 2f_c \pm f_b)$$

Relative Third Harmonic:

$$R_{3a/a} = K_3 + 2L_a - 15.5\text{dB} \text{ (at } 3f_a)$$
$$R_{3b/b} = K_3 + 2L_b - 15.5\text{dB} \text{ (at } 3f_b)$$
$$R_{3c/c} = K_3 + 2L_c - 15.5\text{dB} \text{ (at } 3f_c)$$

Compression and Expansion:

In the foregoing the first order output levels (L_a, L_b, and L_c) have been used as reference levels in expressing relative distortion. It should be carefully noted that these are not the levels that would be measured at f_a, f_b and f_c when third order distortion is present. The effect of the self- and cross-compression (or expansion) components is to reduce (or increase) the actual output at these frequencies as compared with the first order levels, and thus introduce errors in measurements of relative distortion.

In practical measurements, errors due to this effect can be avoided by temporarily removing all input signals except the one at the frequency of measurement (to eliminate cross-compression/expansion effects) or by measuring output levels with a known reduction in input levels (which reduces all distortion). The degree of error to be expected is a function of output level, and is related to other effects of third order distortion as shown below.

Compression:

The degree of compression (assuming k_3 is negative) can be expressed as the dB ratio of the actual output at f_a to the first order output. This ratio is determined by the number of input signals, and by the relative third order distortion expressed by $R_{abc/a}$ (chosen as a convenient measure of third order distortion) as shown in the following table: (See Appendix II, p. 107 for derivation.)

Cross-Modulation:

All the preceding developments have assumed unmodulated input signals. The signals introduced into operating CATV amplifiers are, of course, modulated TV picture and sound signals. The distortion components that occur in this situation are very much affected by modulation. The triple beat between three modulated signals, for example, carries all three sets of modulation components.

One principle allows application of the simplified analysis to the situation where the signals are modulated. The output level of a picture-modulated signal, as normally expressed, describes its maximum excursion (at the tip of sync). Thus, the distortion component levels obtained by using the dBmV levels of the modulated signals in the distortion equations are those that would exist in the worst case, where all sync pulses on the interfering signals momentarily coincided in time.

One important form of distortion, Cross-modulation, occurs only when the input signals are modulated. It is generated by the same effects that produce Cross-compression (or expansion) when the inputs are unmodulated. The interfering test signals used to measure cross-modulation in the NCTA Standard method are 100% square-wave modulated. In this case the degree of modulation on the desired test carrier (which is otherwise unmodulated) can be developed in a reasonably simple way from the CW distortion relationships. This is done in Appendix III, p. 107.

$R_{abc}/_a$ ($= L_{abc} - L_a$)	Total Compression in dB with the Number of Equal Voltage Input Signals Indicated				
	1	2	3	12	20
−20dB	−0.45dB	−1.41dB	−2.50dB	–	–
−25	−0.25	−0.76	−1.32	−9.03dB	–
−30	−0.14	−0.42	−0.71	−3.92	−8.32dB
−35	−0.08	−0.24	−0.40	−1.99	−3.70
−40	−0.04	−0.13	−0.22	−1.06	−1.88
−45	−0.02	−0.07	−0.12	−0.58	−1.01
−50	−0.01	−0.04	−0.07	−0.32	−0.55
−55	< −0.01	−0.02	−0.04	−0.18	−0.31
−60	"	−0.01	−0.02	−0.10	−0.17
−65	"	< −0.01	−0.01	−0.06	−0.10
−70	"	"	−0.01	−0.03	−0.05

Expansion:

The degree of expansion (assuming k_3 is positive) can be similarly expressed, and the results are shown in the following table: (Also see Appendix II for derivation.)

$R_{abc}/_a$ ($= L_{abc} - L_a$)	Total Expansion in dB with the Number of Equal Voltage Input Signals Indicated				
	1	2	3	12	20
−20dB	0.42dB	0.83dB	1.93dB	6.64dB	9.40dB
−25	0.24	0.48	1.14	4.33	6.43
−30	0.14	0.27	0.66	2.69	4.17
−35	0.08	0.15	0.38	1.62	2.59
−40	0.04	0.09	0.21	0.95	1.55
−45	0.02	0.05	0.12	0.54	0.90
−50	0.01	0.03	0.07	0.31	0.52
−55	0.01	0.02	0.04	0.18	0.30
−60	< 0.01	0.01	0.02	0.10	0.17
−65	"	< 0.01	0.01	0.06	0.094
−70	"	"	0.01	0.03	0.054

It is shown in part 1 that, for equal signal output levels the NCTA standard cross-modulation, expressed in dB (symbol XM) is given approximately by this equation:

$$XM = K_3 + 2L + 20 \log_{10} (n - 1)$$

L is the output level of each signal (measured at the peak of modulation when the signal is modulated), n is the total number of input signals, including the unmodulated test signal. This relationship is accurate within ±0.5dB when operating conditions are such that $R_{abc/a} \leqq -20dB$, and when the amplifier meets all the conditions assumed in this analysis.

It is shown in part 2 that, for equal signal output levels the decibel modulation factor (symbol M) is given approximately by this equation:

$$M = K_3 + 2L + 20 \log_{10} (n - 1) - 6dB$$

i.e. M = XM − 6dB. This equation is accurate within ±0.5dB, when $R_{abc/a} \leqq -20dB + 20 \log_{10} (n - 1)$, and the amplifier meets all conditions assumed in this analysis.

CONCLUSION:

This chapter has presented a mathematical analysis of distortion, with particular reference to cable television amplifiers. Although the analysis is based on a simplified mathematical model, which differs from real amplifiers in several respects, the results of the analysis prove to be useful in understanding the behavior of real amplifiers.

The author wishes to express his thanks to Israel Polidi for much help in developing the analysis, and in minimizing errors in the final result.

CHAPTER VI

CROSS-MODULATION IN CATV SYSTEMS

The Nature of Cross-Modulation

The maximum output level that is allowable in CATV system amplifiers is almost always determined by cross-modulation in the picture, "windshield wiper" effects, due to many channels passing through a single amplifier.

Figure 53 may help to understand the nature of this distortion. It shows the variation produced in an unmodulated signal on one channel passing through such an amplifier simultaneously with a modulated signal on another channel. The modulation on channel "B" (the interfering signal) caused a change in the amplifier's gain and modulated the signal on channel "A" (the wanted signal). In the particular case illustrated, the signal on "B" produced notches in the signal on "A" whose depth was about 10% of the peak amplitude of "A". (i.e., dimension "X" is about 10% of dimension "Y").

Cross-modulation is illustrated onto an unmodulated signal because the diagram is clearer for this case. In a real situation this transfer or "crossing" of modulation from the interfering channel to the wanted one results in a weak reproduction of the picture of the interfering channel superimposed on the picture being viewed. Since the receiver's horizontal scanning is synchronized with the wanted signal but usually not with the interfering one, the two horizontal frequencies usually differ slightly, and the interfering picture moves back and forth across the screen, producing slanting bars which give the "windshield wiper" effect.

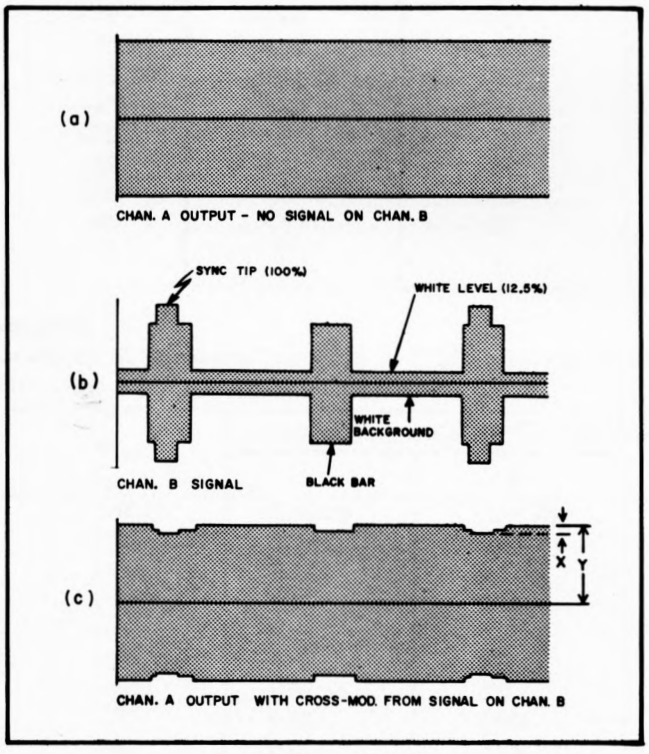


Figure 53. Cross-Modulation.

Fig. 53 shows negative cross-modulation (the weak variation on channel "A" has a polarity opposite to that of the modulation on "B" that causes it). In actual systems or amplifiers the transferred modulation may have either polarity, although in our experience it is more frequently negative.

Expressing Cross-Modulation in Percent:

The modulation of a television broadcast signal follows standards established by the FCC. These standards require that sync tip be held at a constant level regardless of picture content, and that the modulation minimum (white level) be approximately 12.5% of this as illustrated in Fig. 53 (b). Since TV modulation is unsymmetrical, the usual definition for percent modulation is not applicable, and in fact there is no general agreement on the meaning of "percent modulation" as applied to a broadcast TV signal. Some way of measuring cross-modulation and expressing it in numbers must be found if CATV amplifiers are to be rated. Fortunately a reasonable definition of percent cross-modulation is possible without getting involved in the difficulty of defining percent modulation for a TV signal.

Since it is difficult to measure cross-modulation with modulation on the wanted channel, this measurement has usually been done with a c-w signal substituted for the wanted picture signal. Thus Fig. 53 (c) depicts the test signal as it appears when cross-modulation is present. The simplest measure of the amount of cross-modulation in this situation is the ratio of the change in peak voltage (dimension X) produced by cross-modulation to the maximum peak voltage (dimension Y). Since this is always a number smaller than 1 it is conveniently expressed in percent:

Where cross-modulation exists, it results in a variation in the peak voltage of an otherwise unmodulated signal substituted for the wanted carrier. Percent cross-modulation is defined as 100 times the ratio of this variation to the maximum peak voltage. This definition assumes full modulation (from sync level down to white level) of the interfering signal(s).

The measurement of cross-modulation usually requires a receiver, the measurement being made in terms of the variation in detector output as compared with the d-c output. (See, for example, the procedure described on pp. 50 to 53.) With reasonable detector linearity such a measurement will agree with the above definition with acceptable accuracy.

Expressing Cross-Modulation in dB

While modulation of all kinds is usually expressed in percent, and it is often convenient to express cross-modulation in these terms, in many cases a dB expression is best. In such cases, cross-modulation is expressed as so many "dB relative to 100% modulation."

Percent modulation implies a voltage measurement, so the relation between dB and percent is:

$$\text{Cross-mod. (dB rel. to 100\%)} = 20 \log_{10} \left(\frac{\text{\% cross-mod.}}{100} \right)$$

Note that $\frac{\text{\% cross-mod.}}{100}$ is always less than one, and its logarithm is negative, so the dB expression for % cross-mod. is always a negative number. 1% cross-mod., for example, corresponds to −40 dB, 0.1% to −60 dB and so on.

A chart (V1) and tables (V4 and V5) in Chapter XI allow accurate conversion between percent and dB.

Maximum Tolerable Cross-Modulation

As in the case of signal-to-noise ratio, there has been no agreement in the CATV industry on the maximum cross-modulation that can be tolerated in the picture. Bell Telephone Company had a somewhat similar problem in determining the maximum flat video cross-talk permissible in their systems. Carson[1] mentions 52 dB as the ratio of wanted to interfering video signals when the interference is just perceptible to a group of trained observers at a viewing distance eight times picture height. This is based on careful subjective tests reported by Fowler[2].

Although the general effects of video cross-talk and r-f cross-modulation on the viewed picture are similar, they are not the same. The effective cross-talk produced in the video output of a receiver depends not only on the cross-modulation (as defined above) but also on the luminance level of that part of the affected picture signal. For a given percent cross-modulation the effective cross-talk in the lighter parts of the picture will be less than in the darker parts.

Because of the differences between the two effects, further subjective tests would be required to establish the limit for cross-modulation with an accuracy comparable to that of the cross-talk limit. Mathematical analysis indicates that, at the average (grey) level in the picture signal, the effective cross-talk at the receiver's video output will be 6 dB below the cross-modulation at its r-f input. This would suggest a cross-modulation limit of −46 dB for just perceptible interference.

Our practice in the past, based on very limited tests before many of these factors were well understood, has been to design trunk line systems for a maximum cross-modulation of −57 dB. The distribution amplifier was operated at a level where it, too, contributed −57 dB. Our tests assumed that all channels were modulated synchronously. Considering this assumption, and the fact that the −51 dB is 6 dB below the number suggested above, it can be seen that our past operations have been quite conservative in regard to cross-modulation. Perhaps we have relied on this conservatism to keep us out of trouble with all these practical factors which work against system performance but which were left out of our simplified theories!

(1) D. N. Carson, "CATV Amplifiers: Figure of Merit and the Coefficient System." 1966 I.E.E.E. Convention Record, Part I, pp. 87-97.

(2) A. D. Fowler, "Observer Reaction to Video Crosstalk," Journal of the SMPTE, Vol. 57, November 1951, pp. 416-424.

The Change in Cross-Modulation with the Number of Channels

Since there is no standard channel arrangement for which amplifiers are rated, the number of channels used for rating their amplifiers' output capability often varies from manufacturer to manufacturer. The user needs a way of converting ratings given for one number of channels to allow for another number. The way cross-modulation increases with added channels depends on the timing of the synchronizing pulses on the various channels. The worst case, and one that allows easy calculation, is when all synchronizing pulses occur at the same time (synchronous modulation).

When the modulation on all interfering channels is synchronous, the total percent cross-mod. onto a given channel from a number of others is the sum of the individual percent cross-modulations measured separately from each interfering channel.

For example, cross-modulation in a CATV amplifier onto channel 2 from each of eight channels at a certain output level was measured individually as follows:

From Channel	% Cross-Mod.
3	0.18
4	0.15
5	0.17
6	0.17
7	0.16
9	0.14
11	0.13
13	0.05
Total	1.15%

The total cross-mod. on this same amplifier with all nine channels passed simultaneously, at the same levels as before, with all channels synchronously modulated, was measured at 1.0%, which roughly checks the theory.

A second relationship follows from this one for the rather impractical case where the percent cross mod. from each channel is the same:

With synchronous modulation, and an equal cross-modulation contribution from each interfering channel, the total percent cross-modulation is proportional to the number of interfering channels.

Television signals from various broadcasting stations will only be synchronized under unusual conditions, for example when they are originated from a common location. In general, the signals on a CATV system have slightly different horizontal frequencies so that their relative timing changes continuously. This means that the degree of cross-modulation interference in a system changes continuously.

This is illustrated by photos, Figs. 54, 55, 56 and 57 taken from the screen of an oscilloscope connected to the demodulated output of a field strength meter tuned to a c-w carrier with cross-modulation from three non-synchronous signals. Each division on the screen represents 1% cross-mod.

Each of the three interfering signals generated the cross-mod. illustrated in Fig. 54.

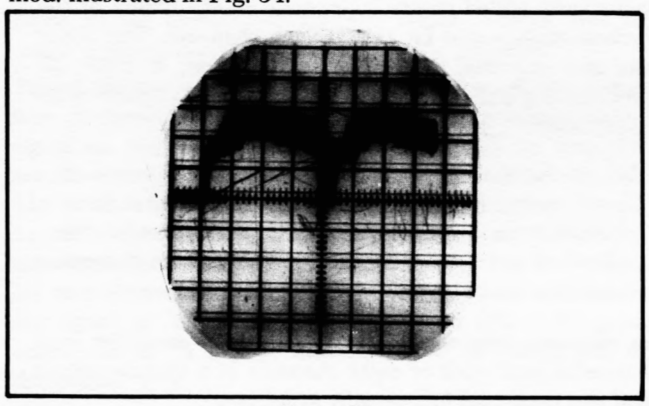


Figure 54.

When all three were connected, and the three sync pulses occurred at different times, the 'scope trace shown in Fig. 55 was obtained. The amplitude of the cross-mod. is about the same as with one channel.

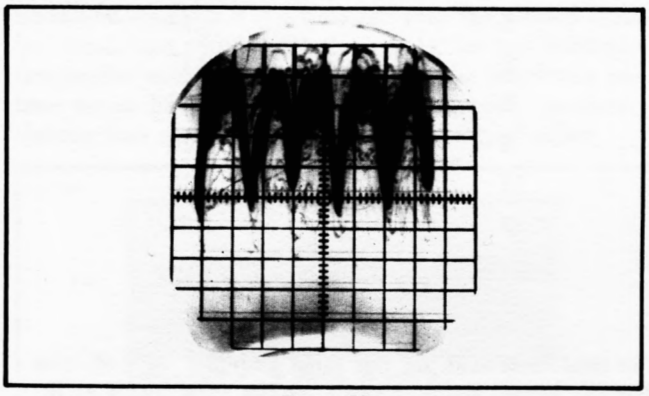


Figure 55.

Observing the trace until two of the three pulses occurred at the same time, the trace in Fig. 56 was obtained. The cross-mod. amplitude is about twice that obtained from one channel.

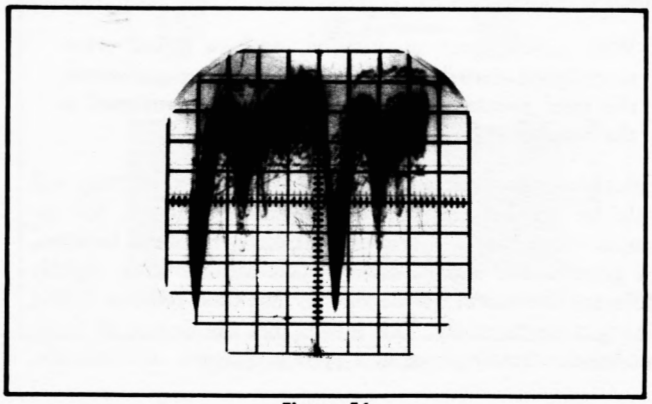


Figure 56.

When all three pulses occurred at the same time (a condition that happened only once in ten minutes) the trace in Fig. 57 was obtained. The cross-mod. was about three times that obtained with a single channel.

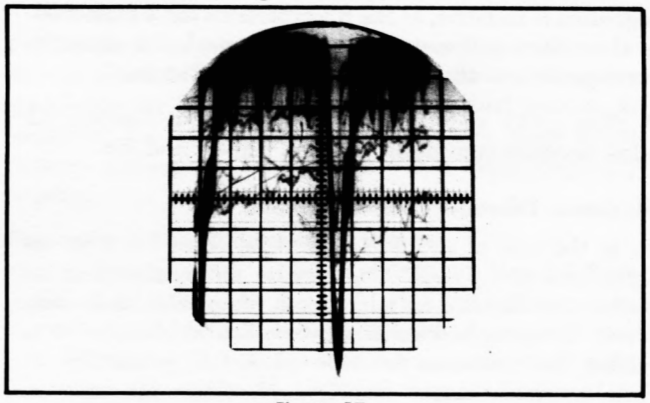


Figure 57.

These photos illustrate the important point that cross-modulation interference in an operating system with many program sources varies widely from moment to moment, and can be related to manufacturers' specifications only by using some kind of "worst case" or rule-of-thumb compromise.

Two such rules are commonly used. They express the cross-mod. in dB for convenience in calculation. Table I shows the increase in cross-mod. with the number of interfering channels for two "compromise" cases. The first shows the worst case where modulation is "synchronous." The second assumes "random" addition where the cross-mod. increases half a dB for each dB increase in the synchronous case. Both cases assume an equal cross-mod. contribution from each interfering channel.

TABLE I

Total Number of Channels	Add dB to two-channel cross-mod.	
	for Synchronous Addition	for Random Addition
1	no cross-mod.	
2	0.0	0.0
3	6.0	3.0
4	9.5	4.8
5	12.0	6.0
6	14.0	7.0
7	15.6	7.8
8	16.9	8.4
9	18.1	9.0
10	19.1	9.5
11	20.0	10.0
12	20.8	10.4

The Increase of Cross-Modulation in a Cascaded Amplifier System

To find the cross-modulation in a long cascade of identical amplifiers, when the characteristics of one amplifier are known, requires a knowledge of the way cross-modulation increases with cascading. This relationship is most easily expressed when cross-mod. is measured in percent:

In a cascade of identical amplifiers, where each amplifier operates at the same output level and the cable loss between two amplifiers equals the gain of each amplifier, the percent cross-modulation increases directly with the number of amplifiers.

Mathematically: $(\%XM)_m = m \times (\%XM)_1$

where: m is the number of amplifiers in cascade

$(\%XM)_m$ is the System Percent Cross-Mod.

$(\%XM)_1$ is the Percent Cross-Mod. of a single amplifier

In other words, if the cross-mod. for one amplifier at normal operating level is 0.1%, two amplifiers give 0.2%, three give 0.3%, and so on. This is true for any system where similar amplifiers are cascaded, and where the single-amplifier cross-mod. can be measured at the system operating output level.

A more general relationship, which applies to any combination of amplifiers, is:

In any system of cascaded amplifiers, the total percent cross-modulation is the sum of the percent cross-modulation figures for the individual amplifiers. The individual percent cross-modulation is measured with the same channel levels and at the same gain settings the amplifier has when in the system.

If, for example, each of two trunk line amplifiers contributes 0.1% XM, and they are followed by a distribution amplifier contributing 0.3% and a line extender at 0.2%, the system cross modulation would be 0.1 + 0.1 + 0.3 + 0.2 = 0.7%.

The Variation of Cross-Modulation with Output Level

It follows from the above that to construct a system with, for example, 50 amplifiers in cascade, requires that each amplifier operate at an output level producing one fiftieth or less of the maximum permissible cross-mod. If this system were limited to 0.5% total cross-mod., each amplifier would have to operate at the output level producing not more than 0.5/50 or 0.01% cross-mod.

Although it is possible, it is difficult to measure 0.01% cross-mod. accurately. Because of this difficulty, it is common practice to measure the cross-mod. in trunk line amplifiers at outputs higher than the normal operating levels. A level is chosen where the cross-mod. is readily measured, and the anticipated distortion at operating level is calculated. This procedure works fine when the amplifier is what we call "well-behaved," that is, the relation between operating level and cross-mod. follows a simple mathematical law. This law says that cross-mod. is a form of "third-order" distortion and that the percent cross-mod. is proportional to the square of the amplifier output voltage.

Mathematically: $\dfrac{\%\,XM_1}{\%\,XM_2} = \left(\dfrac{E_1}{E_2}\right)^2$

where: E_1 and E_2 are two output voltages for a given amplifier,

$\%\,XM_1$ and $\%\,XM_2$ are the corresponding percent cross-modulation figures.

The law is easier to use when the quantities are expressed in decibels:

In a well-behaved amplifier the cross-modulation onto any channel, expressed in dB, decreases 2 dB for each dB decrease in the output levels of all channels.

Mathematically: $XM_1 - XM_2 = 2\,(S_1 - S_2)$

where: S_1 and S_2 are two output levels (in dBmV) for a given amplifier,

XM_1 and XM_2 are the corresponding cross-modulation figures (dB rel. to 100%).

For example, assume that the cross-modulation in a given well-behaved amplifier is −50 dB at + 50 dBmV output. What will it be at +35 dBmV?

Let $S_1 = +50$, $S_2 = +35$, $XM_1 - 50$, then

$XM_2 = XM_1 - 2(S_1 - S_2) = -50 - 2(50 - 35) = -50 - 30 = -80$ dB

Decreasing the output level 15 dB from +50 to + 35 decreases the cross-modulation 30 dB, from −50 to −80 dB.

Conversely, this relationship provides a way of finding, for a well-behaved amplifier, the output level at a given cross-mod. when the cross-mod. at a known output level has been measured.

For example:

Let the distortion XM_1 be −74 dB as measured at an output level S_1 of +40 dBmV; what is the output level S_2 for a cross-mod. XM_2 of −52 dB?

From the above:

$$S_2 = S_1 - \frac{XM_1 - XM_2}{2}, \text{ then for our example}$$

$$S_2 = +40 - \frac{-74 + 52}{2} = +40 - \frac{-22}{2} =$$

$$+40 + 11 = \underline{51 \text{ dBmV}}$$

These rules must be applied with caution since all amplifiers are not well-behaved. Fig. 58 shows plots of output level vs. cross-modulation for two extreme cases. Curve A shows the behavior of a tube distributed amplifier; it is quite well-behaved, as shown by the fact that the cross-mod. changes almost exactly two dB for each dB change in output level.

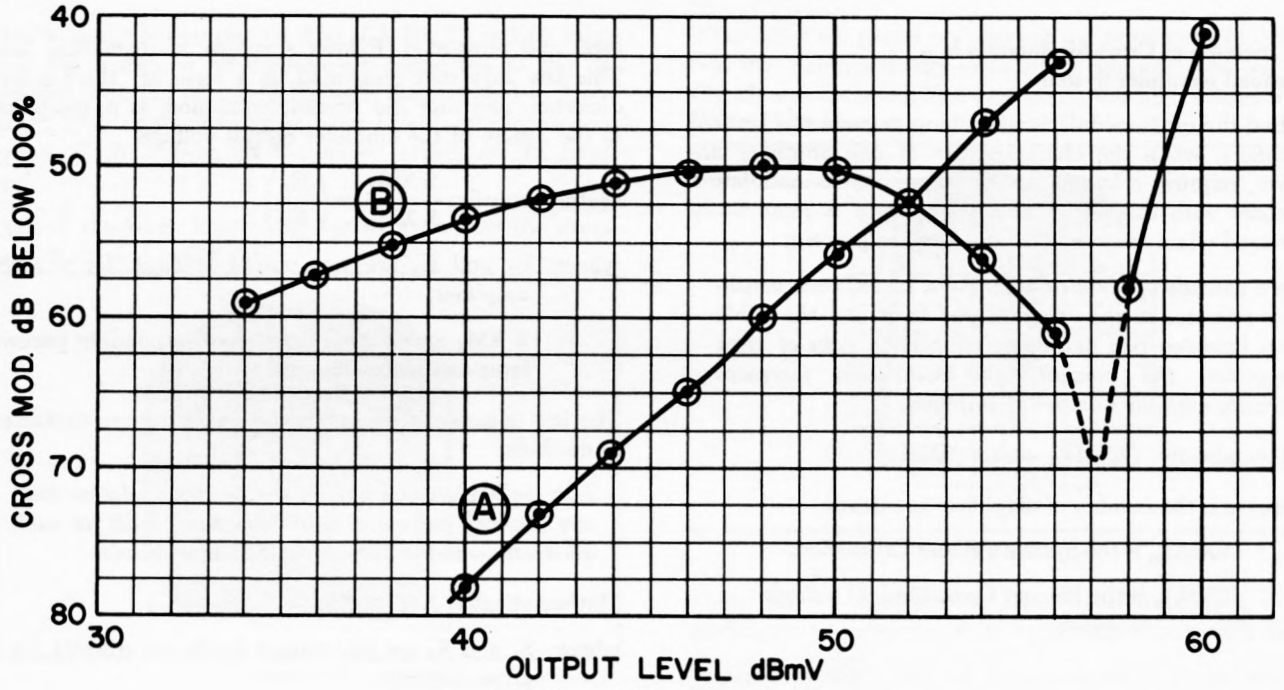


Figure 58. Measurement of Extreme Cases of Cross-Modulation.

Curve B shows the characteristic of a very poorly behaved tube amplifier. As the output is reduced below 60 dBmV, the cross-mod. decreases to a minimum, then increases, finally decreasing at low output levels. Nowhere does it follow a consistent two-for-one law. If cross-mod. were measured on this amplifier for an output level of +56 dBmV, it would read about −60 dB. Applying the rule for well-behaved amplifiers would indicate that the cross-mod. at +46 dBmV output would be −80 dB, whereas it is actually −50 dB, a 30-dB error!

There are two procedures that can be followed to find out if a given amplifier is well-behaved. The simplest is to measure the relation between cross-mod. and output level over the widest possible range, even though this range may not go down to the operating level. If it follows a two for one slope over this range, it is fairly safe to assume this action continues at lower output levels. The more accurate approach is to construct a test system with 8 or 10 amplifiers in cascade, determine the cross-mod. at the desired system level and then use the relation described below to find the individual amplifier cross-mod. from the system cross-mod.

Reduction in Output in a Cascaded Amplifier System

The two rules given above can be put together to show an important relation. One rule says that percent cross-mod. increases directly with the number of amplifiers in cascade, or in decibel terms:

The cross-mod. at the output of a cascade of identical amplifiers increases 6 dB each time the number of amplifiers is doubled.

Or, stated mathematically: System XM (in dB) = single amp. XM + 20 $\log_{10}$ m (where m is the number of cascaded amplifiers).

From the second rule it is apparent that, to reduce the cross-mod. 6 dB, in a well-behaved amplifier, it would be necessary to reduce the output 3 dB, so:

In a cascade of identical well-behaved amplifiers the system cross-modulation can be held to the same level as that of a single amplifier if the level at the output of each amplifier is reduced three dB each time the number of cascaded amplifiers is doubled.

Or, mathematically: for constant XM, system output = single amp. output − 10 $\log_{10}$ m.

These rules can be applied to a cascade of any number of amplifiers by using Table H, as follows:

a) To find maximum output level for the system, subtract the Cascade Factor (C) in the left column opposite the number of amplifiers from the maximum output level of a single amplifier.

b) To find the system cross-mod. (in dB rel. to 100%) add 2C from the right column opposite the number of amplifiers to the cross-mod. for one amplifier at the system output level.

(Note that cross-mod. is expressed in negative numbers, so adding 2C to a given cross-mod. gives fewer dB).

TABLE J

C	No. of Amps in Cascade	2 C	C	No. of Amps in Cascade	2 C	C	No. of Amps in Cascade	2 C	C	No. of Amps in Cascade	2 C	C	No. of Amps in Cascade	2 C
0	1	0	10.41	11	20.82	13.22	21	26.44	14.91	31	29.82	16.13	41	32.26
3.01	2	6.02	10.79	12	21.58	13.42	22	26.84	15.05	32	30.10	16.23	42	32.46
4.77	3	9.54	11.14	13	22.28	13.62	23	27.24	15.18	33	30.36	16.33	43	32.66
6.02	4	12.04	11.43	14	22.86	13.80	24	27.60	15.31	34	30.62	16.43	44	32.86
7.00	5	14.00	11.76	15	23.52	13.98	25	27.96	15.44	35	30.88	16.53	45	33.06
7.78	6	15.56	12.04	16	24.08	14.15	26	28.30	15.56	36	31.12	16.63	46	33.26
8.45	7	16.90	12.30	17	24.60	14.31	27	28.62	15.68	37	31.36	16.72	47	33.44
9.03	8	18.06	12.55	18	25.10	14.47	28	28.94	15.80	38	31.60	16.81	48	33.62
9.54	9	19.09	12.79	19	25.58	14.62	29	29.24	15.91	39	31.82	16.90	49	33.80
10.00	10	20.00	13.01	20	26.02	14.77	30	29.54	16.02	40	32.04	17.00	50	34.00

CHAPTER VII

THE ARITHMETIC OF CASCADED TRUNK-LINE AMPLIFIER SYSTEMS

Introduction

The noise and the cross-mod. relations worked out in the two preceding chapters can be combined to show the factors that determine the maximum length of a cascaded trunk-line system. The system is idealized by assuming that all amplifiers are identical, that they are all "well-behaved," and that they are separated by identical cable lengths each having a loss equalling one amplifier's gain. The use of decibels reduces the mathematics to simple addition and subtraction.

Definitions

Two qualities describe the noise and distortion performance of the system; they determine the quality of the picture at the end of the system, and are, in effect, the ground rules for system design:

R_{min} = *the lowest signal-to-noise ratio (smallest number of + dB) that will be allowed.*

XM_{max} = *the highest cross-mod. level (smallest number of − db) that will be allowed.*

Three more quantities describe the performance of each amplifier:

G_1 = *the operating gain (dB) of one amplifier (taken from manufacturer's specifications or worked out for best cascading).*

F_1 = *measured (or rated) noise figure (dB) of one amplifier at this gain.*

$S_{max(1)}$ = *measured (or rated) output (dBmV) from one amplifier at which cross-mod. = XM_{max} on the worst channel, with the channels to be used on the system measured at the operating gain.*

Starting with these five quantities, a great deal of information about the system can be calculated, including the maximum number of amplifiers that can be cascaded. From this, knowing the cable loss, the maximum system length is easily found.

Noise Relationships (refer to Chapter III for derivation)

Starting with a single amplifier, its noise output (input terminated) is $N_1 = -59 + G_1 + F_1$ (dBmV). The lowest permissible signal output (S_{min}) is found by adding the minimum signal-to-noise ratio R_{min}:

$$S_{min(1)} = N_1 + R_{min} = -59 + G_1 + F_1 + R_{min} \text{ (dBmV)}$$

When many amplifiers are cascaded, the system noise characteristics are found by using the cascade factor (C) which is related to the number of amplifiers in cascade (m) by: $C = 10 \log_{10} m$ (See table on page 15.)

$$\text{System Noise Figure } F_m = F_1 + C \text{ (dB)}$$
$$= F_1 + 10 \log_{10} m \text{ (dB)}$$

$$\text{Noise Output of Last Amplifier } N_m = N_1 + C$$
$$= -59 + G_1 + F_1 + C \text{ (dBmV)}$$

Lowest Permissible Signal Output from last amp. is:

$$S_{min}(m) = N_m + R_{min}$$
$$= -59 + G_1 + F_1 + C + R_{min} = S_{min(1)} + C$$

Cross-Modulation Relationships

(refer to Chapter VI for derivation)

At a given output level, cross-mod. (expressed in percent) increases directly with the number of cascaded amplifiers. For a given system output level S_m, this is expressed (in decibel terms):

system cross-mod. (in dB rel. to 100%)
= (single amp. cross-mod.) + 20 $\log_{10} m$;
thus $XM_m = XM_1 + 2C$

When "well-behaved" amplifiers are used, the system cross-mod. is reduced 6 dB by lowering system output level 3 dB. This says that system cross-mod. can be held at the maximum permissible level (XM_{max}) by reducing system output 3 dB each time the number of amplifiers is doubled:

for system cross-mod. = XM_{max}:

system maximum output $S_{max(m)} =$
$S_{max(1)} - 10 \log_{10} m = S_{max(1)} - C$

How Noise and Cross-mod. Limit System Length

To relate noise and cross-mod., the ideal of "tolerance" is used. The tolerance of a system expresses the variation in level that can be allowed without objectionable picture degradation.

Tolerance is defined as the difference, in dB, between the lowest permissible output level (determined by noise) and the highest (determined by cross-mod.).

For a Single Amplifier:

$$\text{Tolerance } T_{(1)} = S_{max(1)} - S_{min(1)}$$
$$T_{(1)} = S_{max(1)} + 59 - G_1 - F_1 - R_{min}$$

This says that the tolerance of a single amplifier is increased by increasing its maximum output, and by reducing its gain, its noise figure, or the minimum permissible signal-to-noise ratio.

For a Cascaded System:

System *maximum* output: $S_{max} = S_{max(1)} - C$

System *minimum* output:

$$S_{min} = -59 + G_1 + F_1 + C + R_{min}$$

So system tolerance is:

$T_s = S_{max(m)} - S_{min(m)}$;
$T_s = S_{max(1)} - C - (-59 + G_1 + F_1 + C + R_{min})$; then
$T_s = S_{max(1)} + 59 - G_1 - F_1 - R_{min} - 2C$, and
$T_s = T_{(1)} - 2C$

This says that the tolerance of a system is increased by increasing the maximum output of the individual amplifier, and by reducing its gain, its noise figure or the minimum signal-to-noise ratio. It is decreased as more amplifiers are cascaded (C increases).

Maximum Number of Amplifiers

As the number of cascaded amplifiers is increased, a point is reached where the tolerance reaches zero. For this number of amplifiers there is a single critical operating level which alone allows satisfactory pictures. Any increase in level produces cross-modulation; any decrease produces snow. Obviously this is not a practical condition since levels in an actual system inevitably vary from channel to channel (due to frequency response variation) and with temperature as the cable heats and cools. Some tolerance is required to allow for these variations, but the condition of zero tolerance (neglecting these variations) still gives a workable approximation to maximum system length.

Thus, for zero tolerance of a maximum number of cascaded amplifiers the system tolerance

$T_s = 0$ and, from the foregoing:
$T_{(1)} - 2C = 0$; hence $T_{(1)} = 2C$.

This means that zero tolerance for a maximum number of cascaded amplifiers is reached when 2C becomes equal to the tolerance of a single amplifier.

The number of amplifiers that can be cascaded without excessive degradation is increased by all factors that increase the tolerance of a single amplifier.

Optimum System Operating Level

The optimum system operating level is defined as the operating level midway between the maximum output at which cross-mod. becomes intolerable and the minimum at which noise becomes intolerable.

When the number of amplifiers is increased to the point of zero tolerance, only one operating level is possible. This is the same as the optimum operating level for *any* number of amplifiers and is found as shown:

System maximum output $S_{max(m)} = S_{max(1)} - C$;

At zero tolerance $2C = T_{(1)}$;

so $S_{max(m)} = S_{max(1)} - \frac{T_{(1)}}{2}$; that is:

The optimum operating output level for each amplifier in a cascaded system is found by subtracting half the single-amplifier tolerance from the single-amplifier maximum output.

At zero tolerance the maximum and minimum system outputs are equal, so,

since $S_{min(m)} = S_{min(1)} + C$, and
at zero tolerance $2C = T_{(1)}$ then:

$$S_{min(m)} = S_{min(1)} + \frac{T_{(1)}}{2}$$

This seems like a long way round to show that the optimum operating point for an amplifier is half-way between the maximum set by cross-mod. and the minimum set by noise; but it illustrates some of the reasons why this is so, and the calculations that can be made.

CHAPTER VIII

MEASURING NOISE, CROSS-MODULATION AND HUM MODULATION

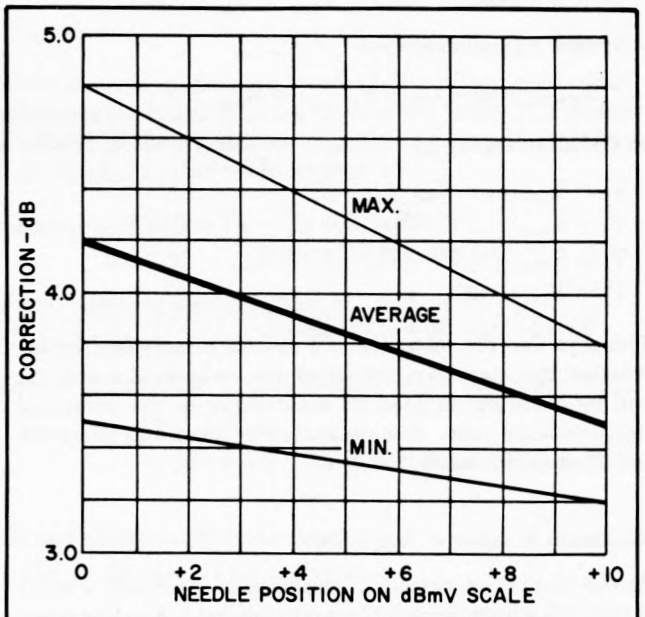
MEASURING NOISE

Noise Level Measurements with a Jerrold Field Strength Meter Model 704B

The 704B was designed to measure the r-f voltage and the dBmV levels of c-w, f-m and television picture signals in cable systems. Although it is not calibrated for noise levels, with suitable correction the meter can be used for this purpose. Two factors prevent it from reading noise levels directly and both must be taken into account in the correction. One source of error is the fact that the bandwidth of the 704B is approximately 0.6 MHz. Since noise levels in CATV are usually specified for a 4-MHz bandwidth, the meter would read approximately 8 dB low if this were the only source of error. (Noise power is proportional to bandwidth, and a power ratio of $4/0.6 = 6.7$ corresponds to 8.2 dB).

A second source of error acting in the opposite direction is the response to noise of the peak detector in the FSM. Since it is designed to respond to the peak of the TV picture signal, it attempts to follow the noise peaks rather than reading the rms noise. Since noise has a higher peak-to-rms ratio than a c-w signal, the detected output reads high, reducing the correction required. As its output is reduced, the efficiency of the detector is lowered and it reads closer to rms so more total correction is needed at the low end of the meter scale.

The curves in Figure 59 indicate the total correction required. They are based on noise calibration tests on ten 704Bs showing the variations as well as the average correction. To use the curves, the level of the noise is measured, reading the meter as if a signal was being measured. The correction corresponding to the needle position on the scale is then added to the measured level to obtain true noise level.



To obtain noise level for 4MHz bandwidth:
1. Measure noise level as if it were a signal.
2. To meter reading add average correction shown opposite needle position.

Figure 59.

To Determine the Signal-to-Noise Ratio in a Trunk-line System

1. Connect the FSM input to the output of the last amplifier (or the output of any other amplifier where the Signal-to-Noise ratio is desired).
2. Disconnect all signals from the input to the first amplifier (except the pilot tone if it is needed for normal ALC operation) and terminate that point.
3. Tune the FSM to the highest and the lowest channels used in the system and read the meter as if a signal were measured.
4. Obtain the corrected noise level for each channel by adding a correction taken from the "Average" curve. Or, for greater accuracy, from a noise calibration of the particular FSM as described below.
5. Subtract the corrected noise level for each channel from the normal channel level at that point in the system to obtain the signal-to-noise ratio at that point.

Noise Calibration of a Field Strength Meter

It is sufficient to use the average curve for *any* 704B if accuracy in the order of plus or minus 1 dB is acceptable. For greater accuracy in noise measurement, the individual Field Strength Meter must be calibrated on a known noise source. One convenient way of doing this is diagrammed in Figure 60. An amplifier having an accurately known noise figure is required. The input to this amplifier is terminated, and its output is connected through a variable attenuator to the input of the second amplifier. The output of the second amplifier is connected to the r-f input of the FSM.

Calibration is made as follows:

1. Tune the FSM to a convenient channel having no local signal. Set it on the −20 dBmV (300 microvolts full scale) range and adjust the Tuner Compensator to the calibrated point.
2. Adjust the variable attenuator to the setting which gives a full-scale reading on the meter (300 microvolts or −10 dBmV).

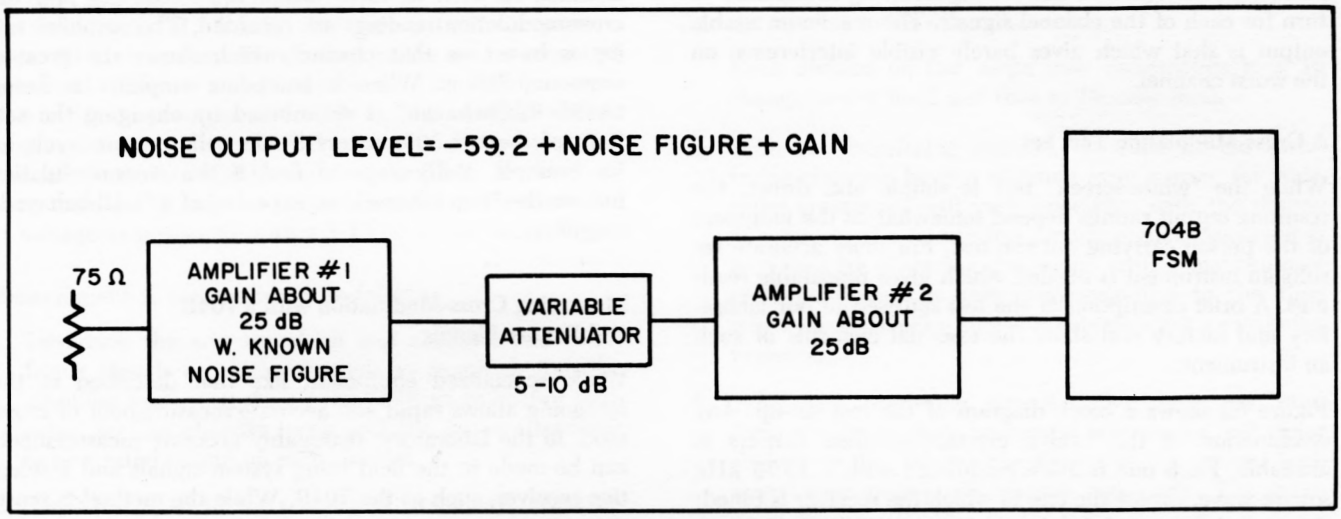


Figure 60. Set-up for Noise Calibration of FSM.

3. With the attenuator at this setting, measure the gain from #1 input to #2 output, and measure the noise figure at #1 input. (If the net gain from #1 input to #2 input is over 15 dB, it is safe to assume that the noise figure of the combination is the same as that of #1 amplifier.)

4. The noise output into the FSM is −59.2 + N.F. + Gain. If, for example, the noise figure measured 8.4 dB, and the net gain were 44.5 dB, the noise output would be −59.2 + 44.5 + 8.4 = −6.3 dBmV.

5. The correction for the FSM at full scale is the number of dBs that must be added to the reading (−10 dBmV) to equal this calculated noise level. (In our example, since the noise level is −6.3 dBmV, the correction is 10 − 6.3 = 3.7 dB.

6. Find the additional correction required at other points on the scale by inserting additional attenuation, 1 dB at a time, and noting how far below the dB marks the needle reads.

MEASURING CROSS-MODULATION

The Basic Test for TV Cross-Modulation

The basic test for cross-mod. is a simple one; Figure 61 shows a block diagram of the set-up. A number of picture signals at the various channel frequencies are combined and fed through the amplifier or system under test. While viewing one of the output signals on a good television receiver, the amplifier output levels are increased, keeping the receiver input constant, until windshield wipers become just perceptible. The level at which this occurs is the maximum usable output of the system.

This test has a weakness in the fact that, when viewing TV programs, windshield wipers can be seen much more readily on some pictures than on others. The accuracy of the test is greatly increased if a c-w signal is substituted for the picture signal on the channel being viewed. This provides a white screen which does not change during the test, so more consistent and critical observations can be made. Since system characteristics are generally not the same for all channels, this test is complete only when it is

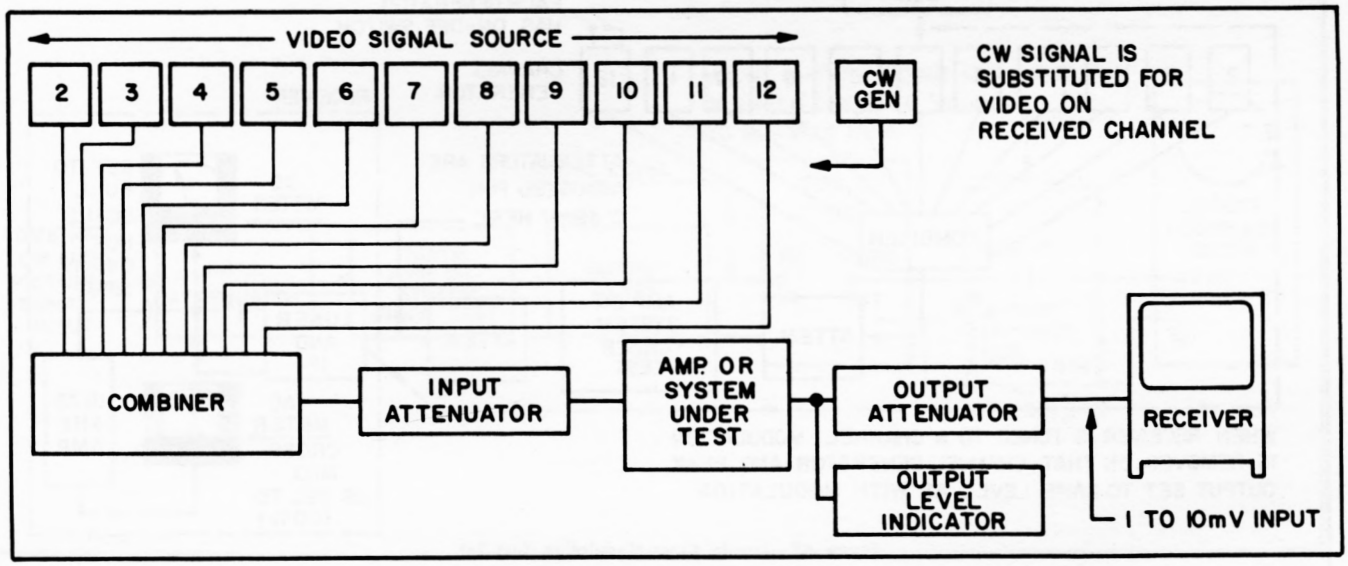


Figure 61. Basic Test for Cross-Modulation.

made on each channel, the c-w signal being substituted in turn for each of the channel signals. The maximum usable output is that which gives barely visible interference on the worst channel.

A Cross-Modulation Test Set

While the "white-screen" test is simple and direct, the resulting output ratings depend somewhat on the judgment of the person carrying out the test. For more accurate results an instrument is needed which gives repeatable readings. A brief description of the test set used in our laboratory and factory will show the essential elements of such an instrument.

Figure 62 shows a block diagram of the test set-up. Any combination of the twelve crystal-controlled carriers is available. Each one is 100% modulated with a 15.75 kHz square-wave, except the one to which the receiver is tuned; this carrier is unmodulated, but its amplitude is the same as the peak amplitudes of the modulated carriers. The receiver gain is kept constant so that, when the channel levels and attenuator settings are adjusted for full scale reading on the d-c meter, the receiver input is standardized at a convenient level (0 dBmV). The amplifier output level in dB is then the same as the dB attenuation of the output attenuator.

The second detector output contains a small 15.75 kHz component due to cross-modulation. This is amplified through a high-gain, narrow-band, 15.75-kHz amplifier, and its level indicated on a meter calibrated in dB below 100% modulation.

To carry out a test, the amplifier is connected, the desired channels turned on, and the channel levels and attenuators adjusted for rated output on each channel. The receiver is tuned to each of these channels successively and the cross-modulation readings are recorded. The amplifier rating is based on that channel which shows the greatest cross-modulation. When a trunk-line amplifier is being tested, its "behavior" is determined by changing the settings of the two attenuators to alter the output levels in, for example, 2-dB steps to find if the cross-modulation follows the "two-for-one" law expected of a "well-behaved" amplifier.

Measuring Cross-Modulation with a 704B and Picture Signals

While specialized equipment like that described in the foregoing allows rapid and accurate measurement of cross-mod. in the laboratory, reasonably accurate measurements can be made in the field using system signals and a selective receiver, such as the 704B. While the method is sensitive enough to measure cross-mod. in complete systems, or in distribution amplifiers, it is not sensitive enough to measure it in trunk line amplifiers at their normal operating levels.

The equipment set-up for this test is diagrammed in Figure 63. The required signals are obtained from the system or directly from the head-end converters. A c-w signal is obtained on the channel being measured by using a c-w signal generator, or switching the converter to a "signal replacement" condition. To make the cross-mod. readings agree with those made on a test set of the type described previously, modulation on all channels other than the one being measured should be synchronous. Where tuneable converters are used, this can be accomplished by tuning them all to receive the same station.

The high-pass filter shown between the video output of

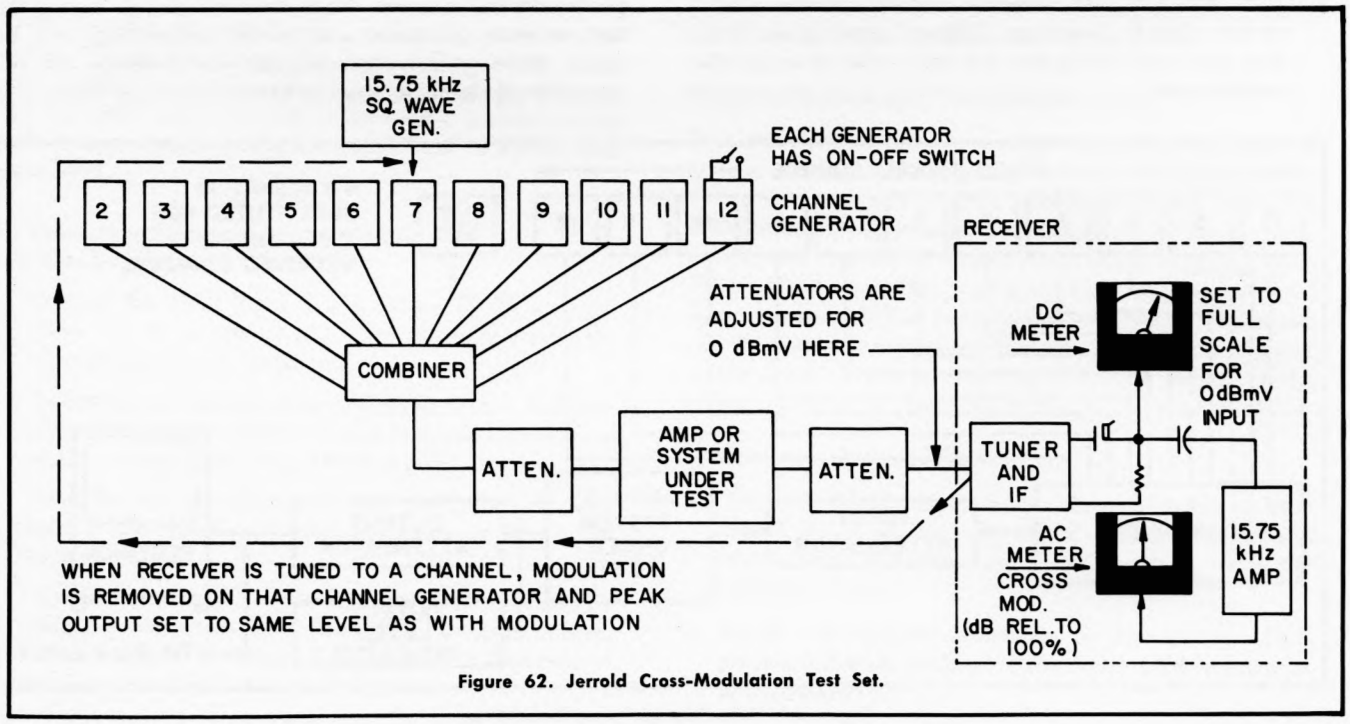


Figure 62. Jerrold Cross-Modulation Test Set.

the FSM and the 'scope passes any cross-mod. components (in the vicinity of 15 kHz) but rejects hum components (near 60 Hz) so they do not obscure the measurement of cross-mod. There is an appreciable i-f (25 MHz) component in the video output of the 704-B. This caused a shift in 'scope centering when the Tektronix 503 'scope we used was set at maximum gain with a-c coupling. If this happens, tune the i-f trap for minimum shift, or for minimum r-f voltage as measured with a VTVM at the 'scope input.

Measurement is accomplished as follows:

1. Introduce the c-w signal on one channel, and interfering signals on other channels as required, into the amplifier under test. Using the 704B as an output indicator, set the channel levels and the input attenuator to give rated output on each channel.
2. Tune the 704B to the c-w signal frequency, insert attenuation in the output attenuator until the level at the input to the 704B is close to +20 dBmV. This level is a compromise; lower levels would have more noise, higher levels would increase the possibility of cross-mod. occurring in the tuner of the 704B. Now adjust the "Tuner Compensator" for full-scale reading on the meter.
3. Close the switch shorting out the high-pass filter, and adjust 'scope gain and centering until the trace is on the bottom line of the screen with the signals temporarily removed from the input, and on the top line with the signals connected. Assuming 10 divisions on the 'scope screen, this sets the relation between c-w level and 'scope deflection so that one division on the 'scope corresponds to a 10% change in c-w level, and thus to 10% cross-modulation.
4. Open the switch, increase the 'scope gain 10 times, center the trace vertically, sync the 'scope to the horizontal line frequency and observe any modulation of the c-w due to the other channels.

   Each division on the 'scope now corresponds to a 1% change in c-w level and thus to 1% cross-mod.
5. With one interfering channel, or when all the interfering channels have a common sync source, the indicated cross-mod. will vary somewhat with the degree of white in the interfering picture signal. Accuracy is increased by observing the 'scope until a maximum of cross-modulation is seen, corresponding to the time when the interfering signal is experiencing a maximum variation.
6. When the interfering signals derive their sync from various sources, their horizontal frequencies will differ slightly so that the relative timing of the various horizontal sync pulses will change constantly. The maximum cross-modulation under this condition will occur when a number of the sync pulses occur momentarily at the same time, and it will be necessary to observe the 'scope trace for some time to estimate the deflection corresponding to this maximum condition.
7. To be sure that there is no cross-modulation in the 704B circuits, nor in the mixing circuits where the various input signals are combined, it is advisable to test the cross-modulation with the input signals connected to the 704B input via the attenuators, with no amplifier. Adjust for equal levels near +20 dBmV at the 704B input, tune to the c-w signal and measure cross-mod. as above.
8. The video output from the 704-B is approximately 1 volt p-p when the meter reads full scale. When using a 'scope with a sensitivity of 1 mV/cm, the gain can generally be increased up to 100 times for a maximum sensitivity of 0.1% cross-mod. per division.

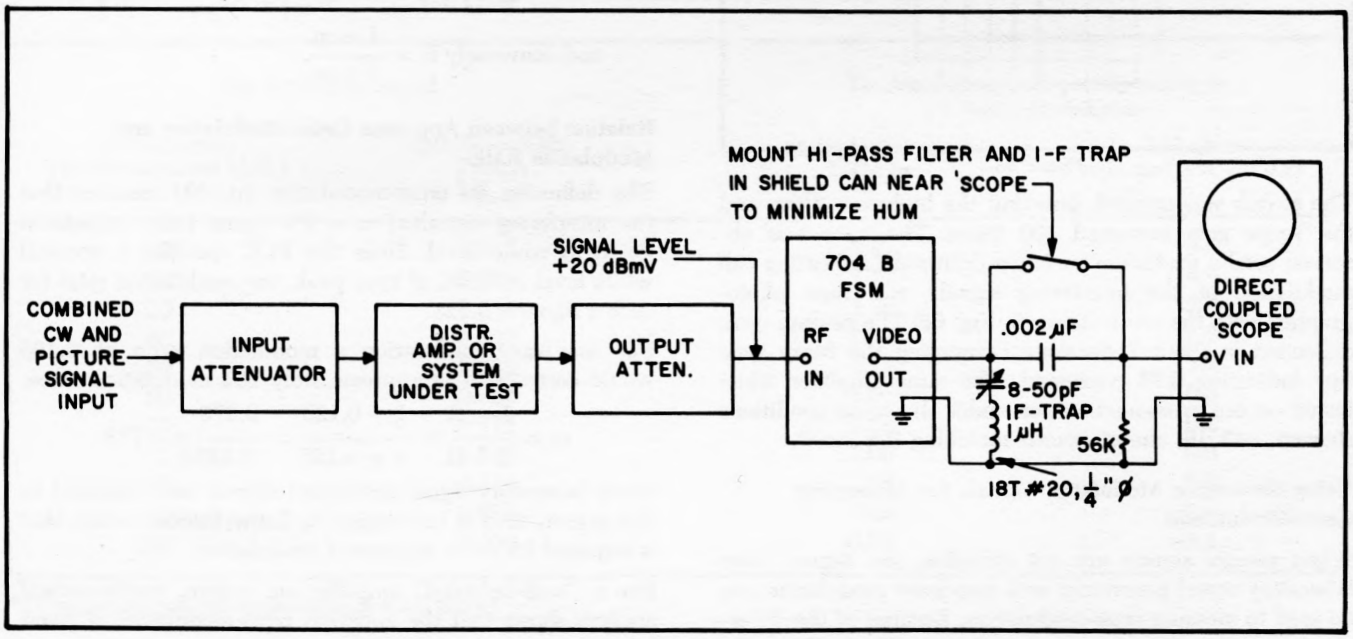


Figure 63. Set-up for Cross-Modulation Measurement with 704-B.

An Example of Cross-Modulation Measurement with TV Modulation

The following photographs illustrate the measurement of the cross-modulation in an amplifier onto a c-w carrier from one video-modulated carrier. The amplifier was a solid-state Model SA-1 with both signals at +60 dBmV (1 volt rms) output. The c-w was on channel 13, the modulated signal on channel 2. The oscilloscope used was a Tektronix Model 503 with a maximum sensitivity of 1 mV/cm.

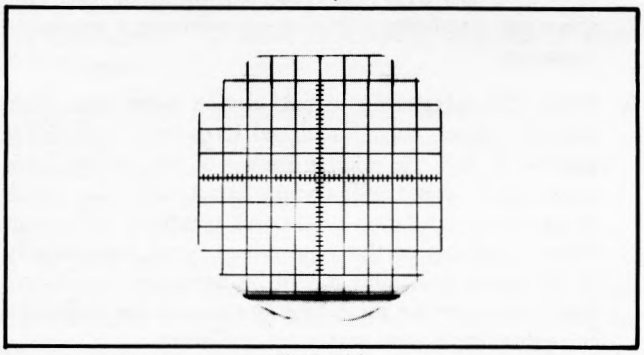


Figure 64.

The 704B was set on the +10 range, reading full-scale on either signal with 40 dB attenuation inserted. With the 704B tuned to the c-w signal, 'scope gain and centering were adjusted so that the trace was on the bottom line (Fig. 64) with the r-f input temporarily disconnected, and moved up 10 divisions to the top line (Fig. 65) with the r-f input connected and the meter at full scale. The 'scope vertical input attenuator was on the 0.1 volt-per-division step.

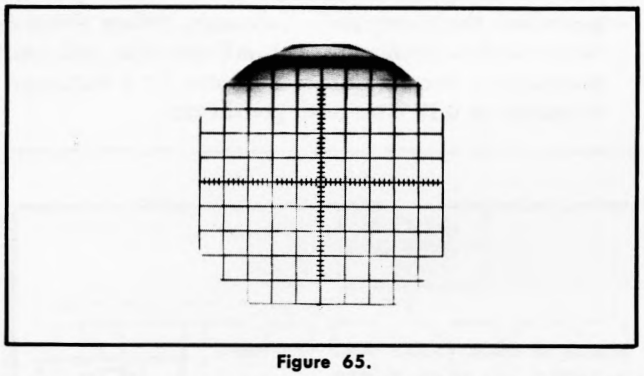


Figure 65.

The switch was opened, inserting the high-pass filter, and the 'scope gain increased 100 times. The trace was observed until a maximum variation occurred (indicating full modulation of the interfering signal) and then photographed with the result shown in Fig. 66. The peak-to-peak deflection is about 7 divisions (averaging the fuzzy sync tip) indicating 0.7% cross-mod. The same amplifier when tested on our cross-mod. tester under the same conditions showed −43 dB, almost exactly matching this result.

Using Sine-wave Modulated Signals for Measuring Cross-Modulation

When picture signals are not available, the signals from laboratory signal generators with sine-wave modulation can be used to measure cross-modulation. Because of the different form of modulation, corrections must be made if the

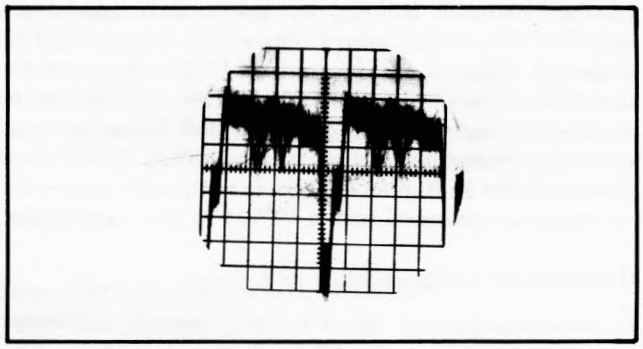


Figure 66.

results of these measurements are to agree with measurements made with TV modulated signals. The following section describes the necessary corrections.

Definition of Terms

E_{max} designates the r-f peak voltage at the modulation maximum;

E_{min} designates the r-f peak voltage at the modulation minimum;

m designates the modulation factor for symmetrical sine-wave amplitude modulation; it is a number between 0 and 1, defined by:

$$m = \frac{E_{max} - E_{min}}{E_{max} + E_{min}};$$

100 m is the percent modulation, between 0 and 100%;

R designates the modulation ratio for any form of amplitude modulation; it is a number between 0 and 1, defined by:

$$R = \frac{E_{min}}{E_{max}};$$

Modulation factor and modulation ratio are related as follows:

Since $E_{min} = RE_{max}$,

$$m = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} = \frac{E_{max} - RE_{max}}{E_{max} + RE_{max}} = \frac{1 - R}{1 + R}$$

and conversely $R = \frac{1 - m}{1 + m}$.

Relation between Apparent Cross-Modulation and Modulation Ratio

The definition for cross-modulation (p. 40) assumes that the interfering signal(s) is a TV signal fully modulated down to white level. Since the FCC specifies a nominal white level at 12.5% of sync peak, the modulation ratio for such a signal is 0.125.

For sine-wave modulation a modulation ratio of 0.125 would correspond to approximately 78% modulation since:

$$m = \frac{1 - R}{1 + R} = \frac{1 - 0.125}{1 + 0.125} = \frac{0.875}{1.125} = 0.778$$

Many laboratory signal generators cannot be modulated to this extent, so it is convenient to know the correction that is required for other degrees of modulation.

For a "well-behaved" amplifier or system, mathematical analysis shows that the apparent cross-modulation is given by:

Apparent cross-mod. (in percent) $= 100\ KE_i^2\ (1 - R_i^2)$

where K is a constant determined by system distortion

E_i is the rms output voltage of the interfering signal at sync tip.

R_i is the modulation ratio of the interfering signal.

Table K is calculated from this relationship. It shows that correction to be applied when a sine-wave modulated signal generator is used to measure cross-modulation in order to find the percent cross-modulation as defined in Chapter VI.

This table also shows that with very little error, no correction is required when the modulation on the interfering carrier is between 70% and 100%. The fact that the interfering carriers on our cross-mod. set are modulated 100%, for example, introduces no appreciable error.

Determining RMS Voltage Corresponding to Peak with Sine-Wave Modulation

Since all level measurements with TV modulated signals are expressed in terms of the rms voltage corresponding to sync peak, it is necessary to express levels in these terms when using other forms of modulation if the measurement results are to agree. Where symmetrical sine-wave modulation is used, levels are commonly expressed in terms of the rms voltage of the unmodulated carrier. In such a case the rms voltage corresponding to the peak of modulation can be found from the relation: $E_p = E_c\ (1 + m)$

where: E_p is the rms voltage at the peak of modulation

E_c is the unmodulated carrier voltage

m is the modulation factor (% modulation ÷ 100).

A Field Strength Meter is usually available and can conveniently be used for measuring output levels. When this is done no correction is needed since the meter measures a modulated signal (with either TV or sine-wave modulation) in terms of the rms voltage corresponding to the modulation maximum.

Examples of Cross-Modulation Measurement with Sine-Wave Modulation

To illustrate the procedure, the cross-modulation in the same amplifier used in the TV signal example was measured using two commercial signal generators. The equipment set-up is diagrammed in Fig. 67. The output signals from the two generators, one on channel 2 and the other on channel 13 picture carrier frequency, were combined through a high-pass, low-pass band-splitting filter to prevent one from cross-modulating the other. The combined signals were introduced into the amplifier and the output levels set at +60 dBmV (1 volt rms at modulation max.) as indicated on the FSM. A modulation frequency of one kilohertz and three different modulation settings were used on the modulated generator. For each one the output setting was readjusted to give +60 dBmV output as read on the FSM.

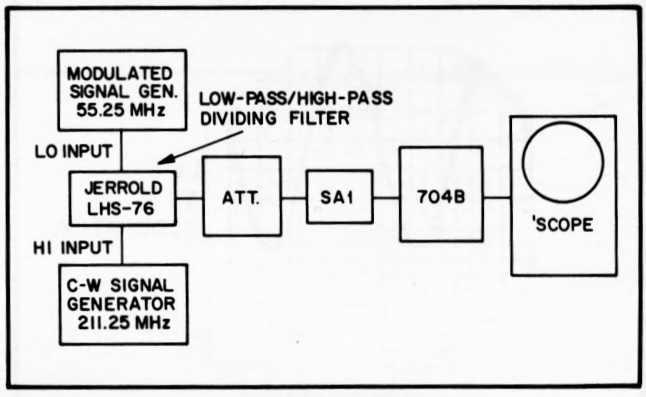


Figure 67.

TABLE K

Cross-Modulation Correction when Modulation of Interfering Signal is Non-Standard

On Interfering Signal		To obtain cross-mod. corresponding to TV Signal Modulation:		
% Modulation (for Symmetrical Mod.)	Modulation Ratio $\left(\frac{E_{min}}{E_{max}}\right)$	Multiply indicated % XM by:	or	Add dB to indicated XM (in dB)
10	0.818	2.97		9.5
20	0.666	1.77		4.9
30	0.538	1.39		2.9
40	0.429	1.21		1.7
50	0.333	1.12		1.2
60	0.250	1.06		0.5
70	0.177	1.02		0.2
77.8*	0.125	1.00		0.0
80	0.111	1.00		0.0
90	0.053	0.99		−0.1
100	0.000	0.99		−0.1

*Corresponding to full modulation of a TV Signal.

Fig. 68 shows 'scope photos indicating the demodulated output of the FSM when tuned to the interfering (modulated) signal. In each case the 'scope was operated in the d-c mode, with gain and centering adjusted so that 0 input corresponded to the bottom line on the screen and 1 volt rms to the top line. Note that, since the maximum is at 1.0 volt in each case, the voltage at the minimum should equal the modulation ratio (0.54 for 30% modulation, and 0.33 for 50% modulation).

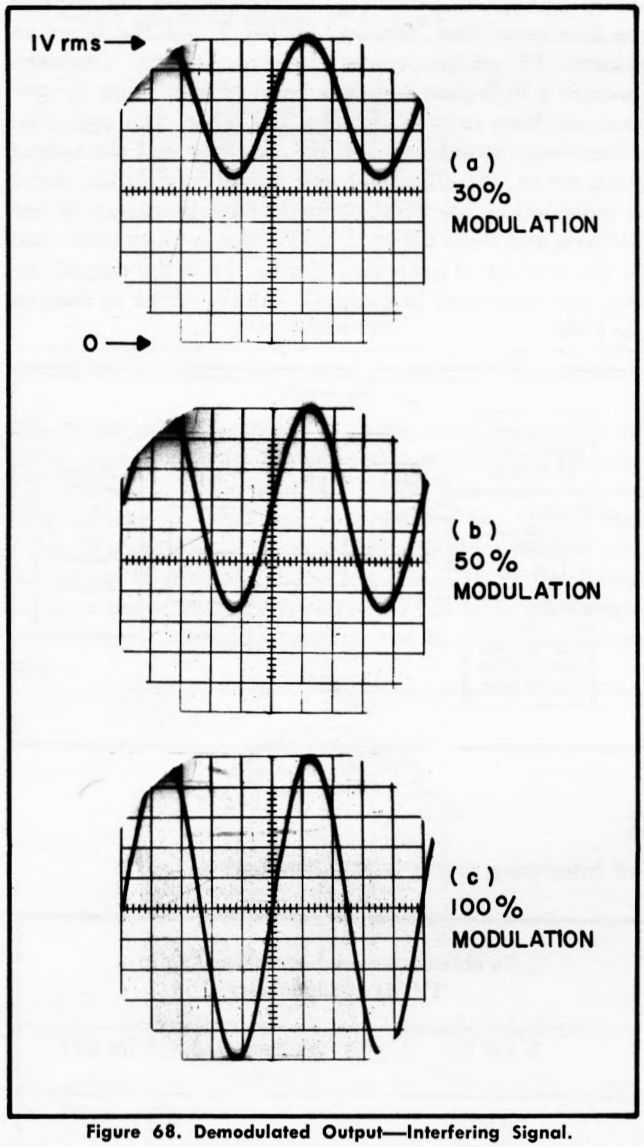


Figure 68. Demodulated Output—Interfering Signal.

Fig. 69 shows 'scope photos indicating the demodulated output of the FSM when tuned to the wanted (c-w) signal. In each case the 'scope was operated in the a-c mode and the gain increased so that each division corresponds to 0.1% cross-modulation. Applying the correction factors from Table K to each measurement gives the following result:

% Modulation of Interfering sig.	Apparent % Cross-mod.	Correction	Corrected % Cross-mod.
30%	0.5%	1.39 ×	0.7%
50%	0.6%	1.11 ×	0.67%
100%	0.7%	1.00 ×	0.7%

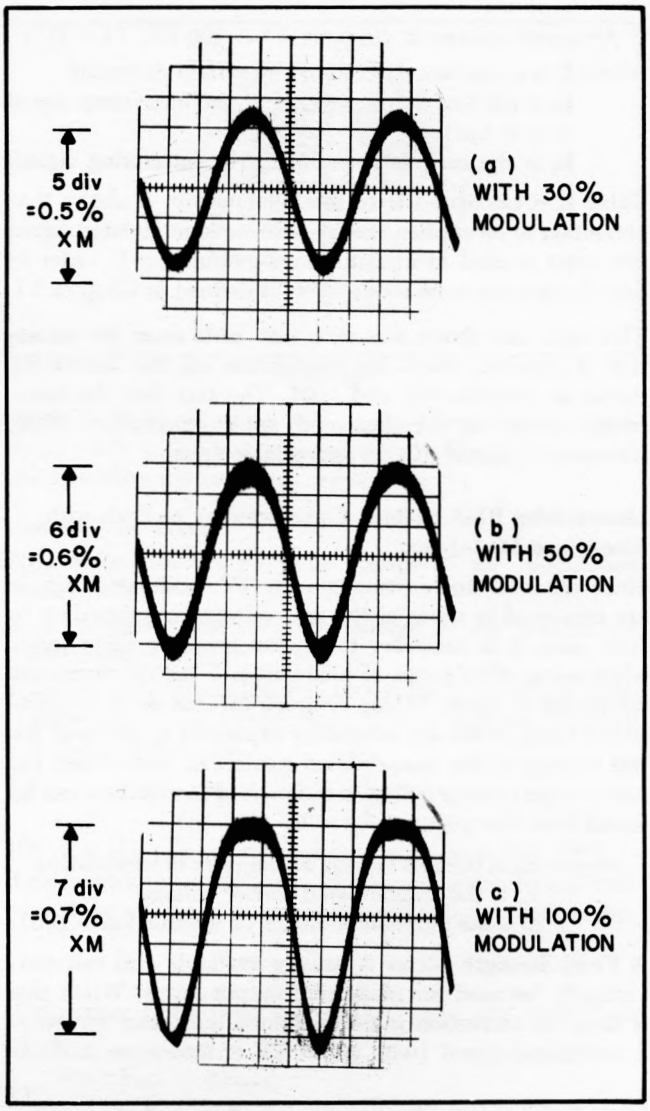


Figure 69. Demodulated Output—CW Signal.

Comparing these results with those obtained on the same amplifier with the cross-mod. tester and with TV signal modulation, it is apparent that there was good agreement.

MEASURING HUM MODULATION

Measurements with a 704B Field Strength Meter

Since most CATV amplifiers are powered with 60 cycle a-c, the possibility exists that power supply ripple will modulate the signal going through the amplifier. Hum modulation can show up on the customer's receiver as horizontal bars that move slowly up or down, so it is necessary to test amplifiers and systems to be sure this effect is not present.

With a direct-coupled 'scope and a hum-free source of c-w signal, a 704B field strength meter can be used for measuring hum modulation. Because some hum is inherent in the instrument, the test is limited to relatively high levels of hum modulation (−50 dB or worse). Thus the 704B can be used for testing hum modulation in complete systems, but is not good enough for testing individual amplifiers intended for trunk line service.

For testing hum modulation, proceed as follows:

1. Connect the Signal source to the input of the amplifier or system under test, and the 704B to its output, as shown in Fig. 70.

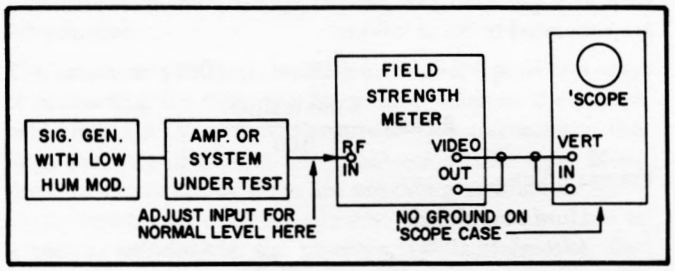


Figure 70.

2. Set the source to a convenient frequency (the center of the band is usually a good choice), and adjust its output so the amplifier or system output is at normal level.

3. Connect the video output of the 704B to the 'scope vertical input with a shielded lead as shown on the diagram. To minimize stray hum loops, be sure there is no other ground on the case of the 'scope. If it has a three-pin power plug, use a 2-pin adapter (which has no ground pin). Sync the 'scope to the "line" at a frequency of 30 or 60 cycles.

4. Set the 704B to "Manual Gain" and adjust gain until meter reads full scale (100). Now adjust 'scope gain and centering so that, with the signal source temporarily disconnected, the trace is on the bottom line of the 'scope screen, and with the source re-connected it goes up to the top line. Assuming the screen has 10 divisions, this adjustment sets the relation between 'scope deflection and c-w level so that each division on the screen represents a 10% change in level. Since hum modulation is usually symmetrical (varying both above and below the unmodulated level) percent modulation follows the rule:

$$\text{percent mod.} = 100\,m = 100 \times \frac{E_{max} - E_{min}}{E_{max} + E_{min}}$$

Since the average (or unmodulated) level is $\frac{E_{max} + E_{min}}{2}$, and

the peak-to-peak variation $= E_{max} - E_{min}$,

it follows that: $\text{percent mod.} = 100 \times \frac{\text{p-p variation}}{2 \times \text{ave. level}}$

$$= 50 \times \frac{\text{p-p variation}}{\text{unmodulated level}}$$

In this case the 'scope has been adjusted so that the unmodulated level corresponds to 10 divisions, so:

$$100\,m = 50 \times \frac{\text{p-p variation (in div.)}}{10 \text{ div.}}$$

$$= 5 \times \text{p-p variation (div.)}$$

Thus a peak-to-peak variation of 10 divisions would represent 50% modulation, 2 divisions would represent 10% and so on.

5. For convenient measurement, switch the 'scope to a-c coupling without changing the gain, and center the trace vertically. If the % mod. is so low that it cannot be measured, increase the gain of the 'scope 10 times.

   Now percent mod. = 0.5 x peak-to-peak variation.

6. To be sure the signal source, the FSM or the 'scope is not producing a hum indication, it is a good idea to test the system first with the source output connected directly to the FSM. Under this condition, the hum modulation should be well below that measured on the amplifier or system, if that measurement is to be trusted.

Example: The 'scope photographs in Figs. 71 to 74 illustrate the technique.

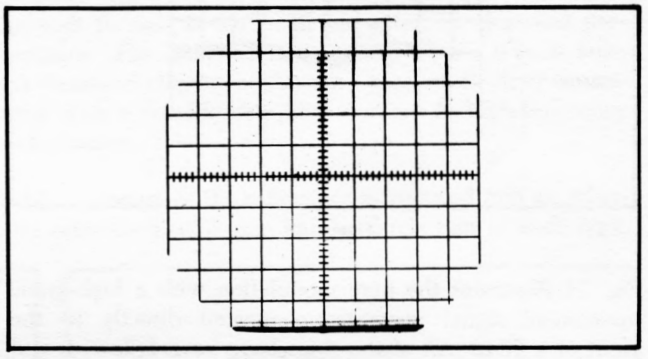


Figure 71.

Fig. 71 shows the trace at the bottom of the screen with no input to the amplifier.

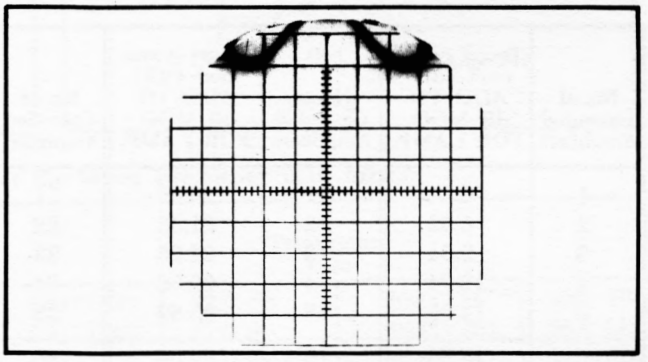


Figure 72.

Fig. 72 shows the trace with the input set for normal amplifier output, and 'scope gain is set so the average deflection is 10 divisions.

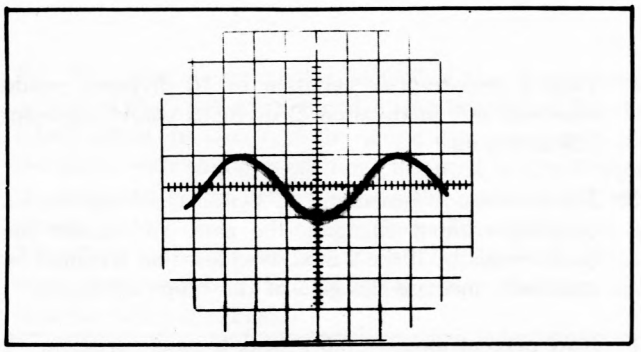


Figure 73.

Fig. 73 shows the 'scope trace centered, with no change in gain. The peak-to-peak deflection is 2 divisions, indicating modulation of 5 x 2 divisions or 10%: This degree of hum modulation would be excessive in an amplifier intended for CATV use; the photo was made while using an amplifier whose hum had been increased above normal by removing a filter capacitor.

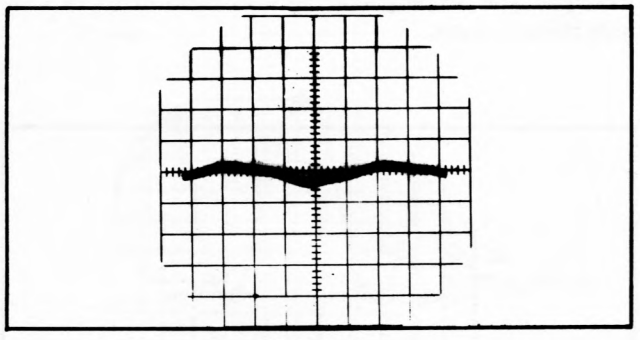


Figure 74.

Fig. 74 illustrates the hum modulation with a high-grade commercial signal generator connected directly to the input of a 704B. All of the steps have been followed, and the scope gain increased 10x, so the percent modulation indicated, with a deflection of about 0.7 div. p-p is about 0.5 x 0.7 or about 0.35%, which is quite good.

Expressing Hum Modulation in dB

It is often convenient, particularly when dealing with cascaded systems, to express hum modulation in dB rather than as a percent. The percent figures from measurement are converted to dB as follows:

$$\text{Hum Modulation (dB rel. to 100\%)} = 20 \log_{10} \frac{\%\ \text{modulation}}{100}$$

For example:

Hum Modulation (dB rel. to 100%)	% Modulation
−6	50.0
−20	10.0
−40	1.0
−60	0.1

(See curve p. 49).

Hum Modulation in Cascaded Amplifier Systems

When each one of a chain of cascaded amplifiers produces a certain amount of hum modulation, the system hum modulation will increase directly with the number of amplifiers, unless the phase of the modulation from some of the amplifiers is different from that of others. To be safe, it is good practice to calculate system hum modulation based on the "worst case" where they are all in phase.

In this worst case, the percent hum modulation is doubled each time the number of amplifiers is doubled; or in dB terms, the hum modulation (in dB rel. to 100%) increases 6 dB each time the number of amplifiers is doubled (i.e. the negative dB number gets smaller). To aid in system calculations, Table L shows the increase in hum modulation for up to 50 cascaded amplifiers.

TABLE L

INCREASE OF HUM MODULATION IN A CASCADED AMPLIFIER SYSTEM

WORST CASE:

ASSUMING IDENTICAL AMPLIFIERS, AND PHASED HUM

No. of Cascaded Amplifiers	To get system mod. (dB) ADD TO dB MOD. FOR 1 AMP.	No. of Cascaded Amplifiers	To get system mod. (dB) ADD TO dB MOD. FOR 1 AMP.	No. of Cascaded Amplifiers	To get system mod. (dB) ADD TO dB MOD. FOR 1 AMP.	No. of Cascaded Amplifiers	To get system mod. (dB) ADD TO dB MOD. FOR 1 AMP.	No. of Cascaded Amplifiers	To get system mod. (dB) ADD TO dB MOD. FOR 1 AMP.
1	0	11	20.82	21	26.44	31	29.82	41	32.26
2	6.02	12	21.58	22	26.84	32	30.10	42	32.46
3	9.54	13	22.28	23	27.24	33	30.36	43	32.66
4	12.04	14	22.86	24	27.60	34	30.62	44	32.86
5	14.00	15	23.52	25	27.96	35	30.88	45	33.06
6	15.56	16	24.08	26	28.30	36	31.12	46	33.26
7	16.90	17	24.60	27	28.62	37	31.36	47	33.44
8	18.06	18	25.10	28	28.94	38	31.60	48	33.62
9	19.09	19	25.58	29	29.24	39	31.82	49	33.80
10	20.00	20	26.02	30	29.54	40	32.04	50	34.00

CHAPTER IX

REDUCING THE EFFECTS OF REFLECTION IN CATV FEEDERS

Introduction

The pressure type tap is a convenient and economical way of connecting the customer house drop cable to the feeder cable in a CATV system. Because of this convenience the large majority of taps in use today are of this type. Hundreds of thousands of them are providing satisfactory service in systems all over the country. Unfortunately there is a penalty attached to the pressure tap's convenience. Because it must tap into the feeder cable with no opportunity for series compensation, the pressure tap inevitably introduces reflections into that cable. This chapter shows how these reflections can be minimized by careful tap design, and how their adverse effect on the transmission of picture signals can be greatly reduced by grouping taps in optimum arrangements.

Improvements in Pressure Tap Design

Until recently Jerrold has manufactured four basic types of pressure taps. The earliest designs, Models PTR and PTC, employed a series resistor or a series capacitor connecting the pressure point to the center conductor of the drop line, as illustrated in Fig. 75. The resistor tap (PTR) was used for line-to-tap losses of 30 dB and over, the capacitive tap for lower loss magnitudes. This design had the advantages of simplicity and low cost. While the capacitive tap had high efficiency (i.e., the loss on the feeder line, for a given line-to-tap loss, was low compared to that of other designs) it introduced reflections on the feeder that were much worse than those introduced by transformer taps having the same line-to-tap loss.

Fig. 76 shows the schematic diagram of a transformer tap. A tightly coupled auto-transformer steps up the impedance of the load to a high, and essentially resistive, impedance bridging the feeder line. A coupling capacitor isolates the primary at low frequencies and a series resistor raises the output impedance so the tap acts as a well-matched source for the drop line. Jerrold manufactures two kinds of transformer taps which are similar electrically but differ mechanically. The CMT tap is convenient as a replacement for the older taps. It is mechanically interchangeable with the PTR and PTC. However, the ⅜ inch hole into which this unit threads is too small for optimum electrical performance. The BMT transformer tap uses a ½ inch hole; this increased clearance allows a reduction in stray capacitance with a considerable improvement in high-frequency performance.

Table M compares the reflections introduced into an otherwise reflectionless 75-ohm line by single taps of each type.

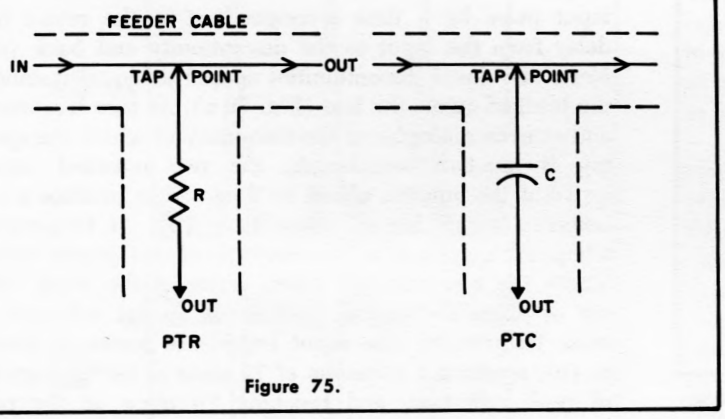


Figure 75.

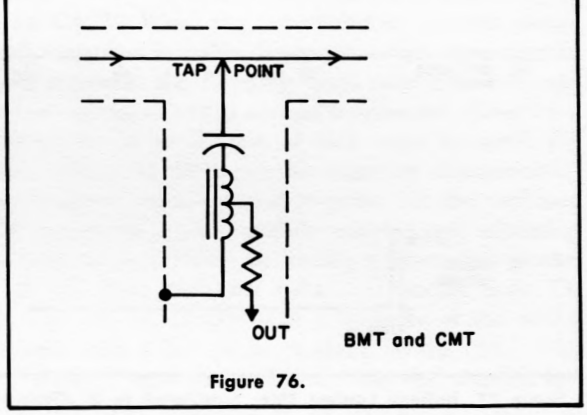


Figure 76.

TABLE M **Reflection Introduced into a Feeder by One Tap at the Worst Frequency (216 MHz)**

Loss From Line to Tap at 216 MHz	Resistive and Capacitive Taps		Transformer Taps			
35 dB	PTR(6)	26. dB	CMT(35)	22.0 dB	BMT(25)	26.0 dB
30 dB	PTR(3)	25.5 dB	CMT(30)	21.0 dB	BMT(20)	28.0 dB
25 dB	—		CMT(25)	22.0 dB	BMT(16)	29.0 dB
20 dB	PTC(W)	19.5	CMT(20)	21.6 dB	BMT(12)	26.7 dB
16 dB	PTC(R)	16.4	CMT(16)	21.4 dB	BMT(35)	25.4 dB
12 dB	PTC(Y)	14.2	CMT(12)	19.5 dB	BMT(36)	21.1 dB

Note: Reflection figures on this table were obtained by measurement of production units selected at random. Published specifications show somewhat greater reflection in each case.

Notice the substantial reduction in reflection accomplished by the use of transformer taps at low tap losses. At a 16-dB tap loss, for example, the reflection from the CMT is nearly 6 dB less than that from the PTC, and that from the BMT is nearly 10 dB less. For tap losses above 30 dB, where resistive taps were used, the transformer taps do not show the same improvement, but still have the important advantage of providing a back-matched source.

Periodicity

To understand reflections on CATV feeders it is essential to understand "periodicity," the accumulation of reflections from equally spaced discontinuities. A number of simple examples may help to explain the effect. Fig. 77 illustrates conditions existing on a lossless 75-ohm transmission line perfectly terminated with a 75-ohm resistor. There is no reflection at any frequency (b), so the input impedance is constant at 75 ohms (c), and the application of a pulse to the input creates no echo (d).

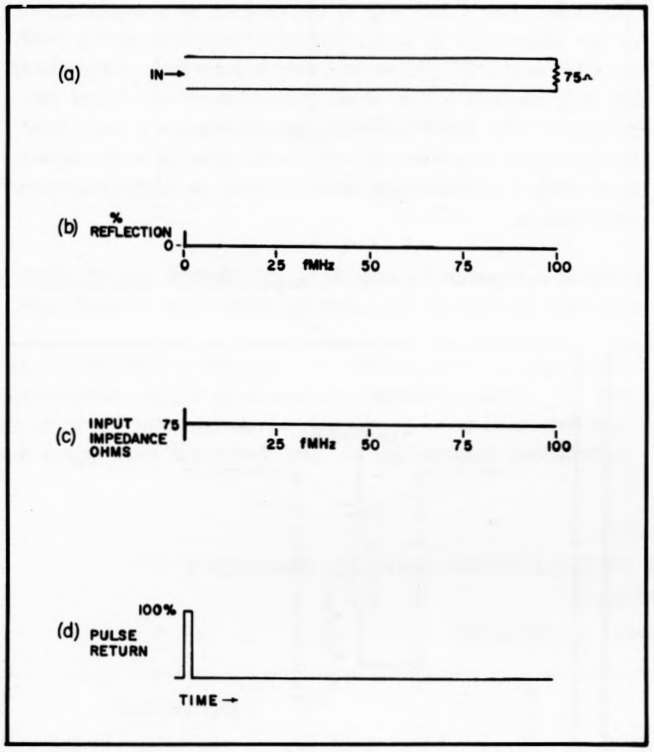


Figure 77. Uniform Lossless Line, Terminated in its Characteristic Impedance, No Discontinuity.

Now consider what happens when a 3700-ohm resistor is bridged across the line at a distance from the input equal to one-half wavelength at 25 MHz (Fig. 78 a). This discontinuity across a 75-ohm line produces a constant 1% reflection at all frequencies (b); this results in a VSWR of 1.02 and as a result the input impedance varies from a minimum of 73.5 ohms (75 ÷ 1.02) when the reflected voltage wave arrives at the input 180° out of phase with the input, to a maximum of 76.5 ohms (75 × 1.02) when the two waves arrive in phase (c). The application of a pulse to the input results in a single echo following the

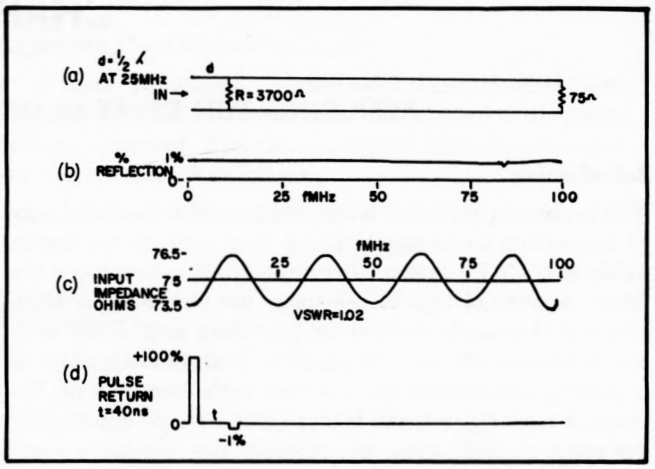


Figure 78. Uniform Lossless Line, Terminated, 1 Discontinuity.

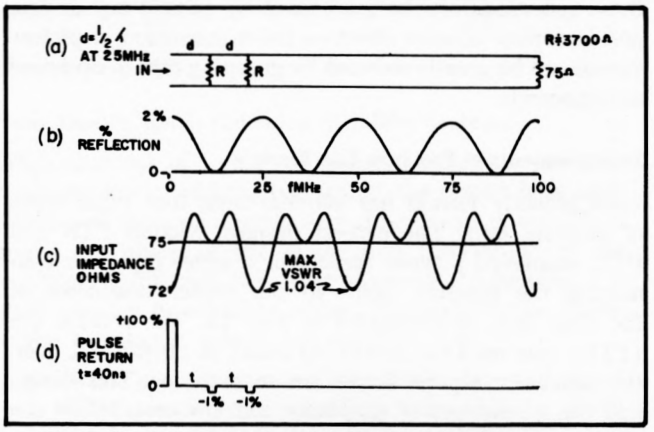


Figure 79. Uniform Lossless Line, Terminated, 2 Discontinuities.

input pulse by a time corresponding to the round trip delay from the input to the discontinuity and back (d). Next, two equal discontinuities spaced at equal distances are bridged across the line (Fig. 79 a). At zero frequency, and at even multiples of the frequency at which the spacing is one-half wavelength, the two reflected waves arrive at the input in phase, so they add to produce a net reflection twice that of either wave (b). At frequencies where the spacing is an odd multiple of one-quarter wavelength the two reflected waves arrive at the input 180° out of phase and cancel, so there is no net reflection at those frequencies. The input impedance varies as shown in (c), reaching a minimum of 72 ohms at the frequencies of peak reflection, and touching 75 ohms at the odd quarter-wavelength frequencies where there is no reflection. Following the input pulse there are two echoes (d).

Four discontinuities, Fig. 80(a) produce complicated variations in reflection (b) and impedance (c). Certain general tendencies become clear. With many equally spaced discontinuities the reflections add to produce relatively narrow peaks of reflection centered at frequencies that are multiples of the one where the spacing is one-half wavelength. Between peaks there are relatively broad ranges where the total reeflction is low. This becomes even more pronounced with eight discontinuities (Fig. 81). This pattern with widely spaced narrow peaks of reflection is characteristic

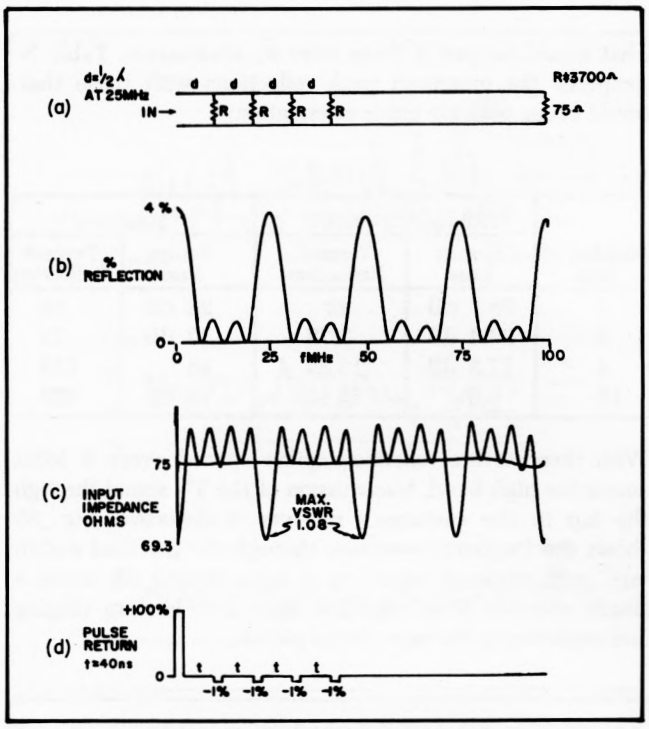


Figure 80. Uniform Line, Terminated,
2 Equally Spaced Discontinuities.
4 Equally Spaced Discontinuities.

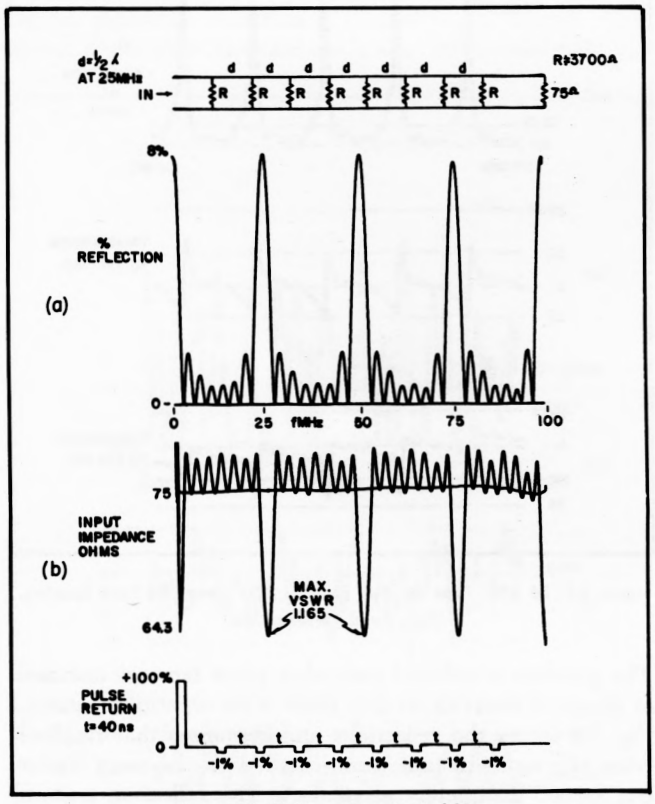


Figure 81. Uniform Terminated Line,
8 Equally Spaced Discontinuities.

of "periodicity," showing up whenever there are many equally spaced sources of reflection. Fig. 82 summarizes the dependence of the reflection pattern on the number of taps.

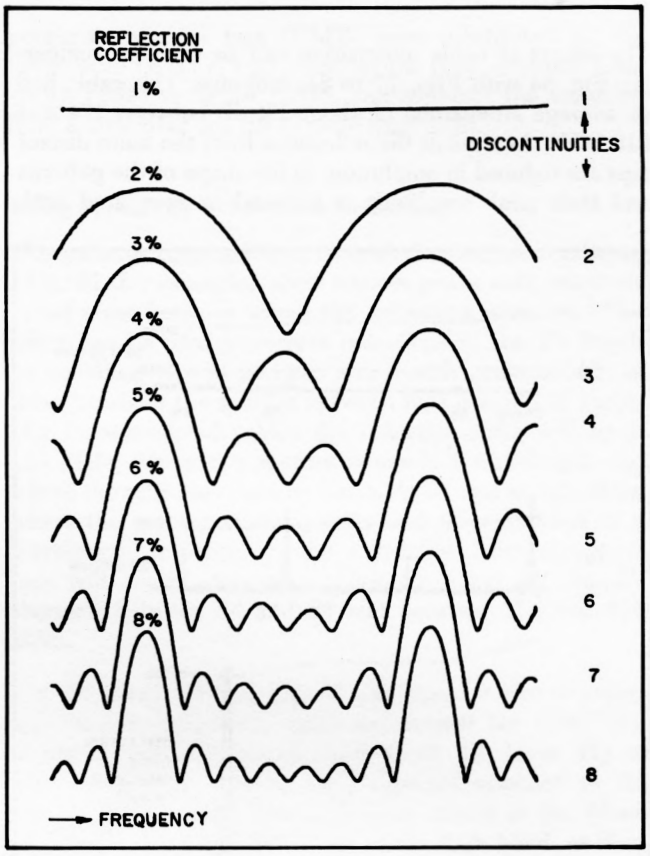


Figure 82. Increase in Reflection with 1 to 8
Equally Spaced Discontinuities.

Periodicity in Cable

This effect shows up as a problem in the manufacture of cable for CATV. When the manufacturing process results in small variations in cable dimension which are repeated at equal intervals, the resulting small reflections can add to produce severe effects at certain frequencies. Great care is required in the production of such cable to avoid the problem. Figure 83 illustrates the reflection characteristics of three reels of cable selected to point out the problem. Fig. 83 (a) shows a very carefully selected reel exhibiting a minimum of the problem by having a return loss greater than 40 dB (less than 1% reflection) across both TV bands. Fig. 83 (b) is typical of a majority of the cables being used, with a few peaks reaching 30 dB (3%). Fig. 83 (c) shows a most unusual case. This reel showed less than 26 dB (5%) reflection at all frequencies except at 195 MHz, where there was an 8 dB (45%) peak! Note the similarity between the shape of these reflection peaks and those shown in the preceding "synthesized" samples.

Periodicity Problems with Pressure Taps

If care is not exercised, periodicity can cause problems when pressure taps are installed on a feeder. With telephone poles spaced at regular intervals along the street there is a tendency to space taps at regular intervals along the feeder cable. This can cause severe trouble. Fig. 84 shows the measured build-up of reflections with various numbers of BMT taps spaced exactly 50 feet apart on a feeder of one-half inch foam-insulated cable.

The effects of cable attenuation can be seen by comparing Fig. 84 with Figs. 77 to 81, inclusive. This cable had an average attenuation of about 1.3 dB between 174 and 216 MHz. As a result the reflections from the more distant taps are reduced in amplitude, so the shape of the patterns and their peak amplitude is reduced as compared with what would happen if there were no attenuation. Table N compares the measured peak reflections with those that would occur with no cable attenuation:

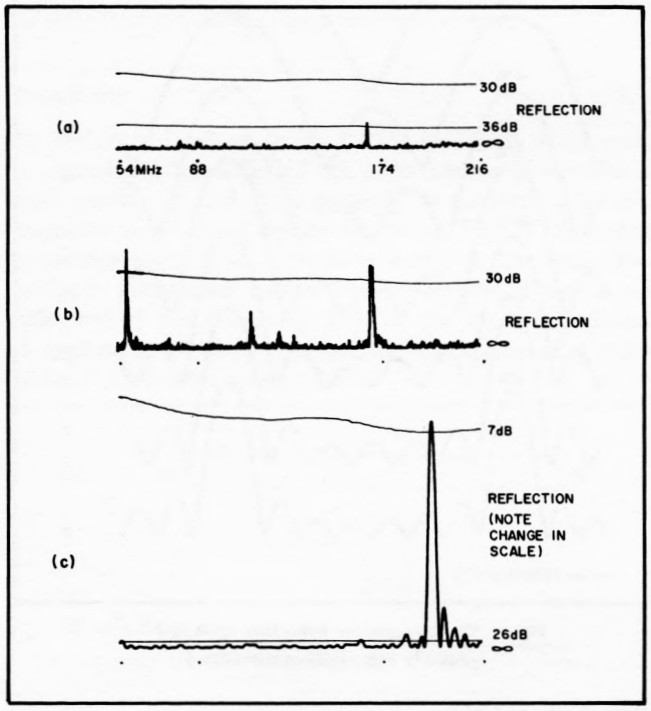


Figure 83. Reflection vs. Frequency— 3 Reels of CATV Cable Showing Effects of Periodicity.

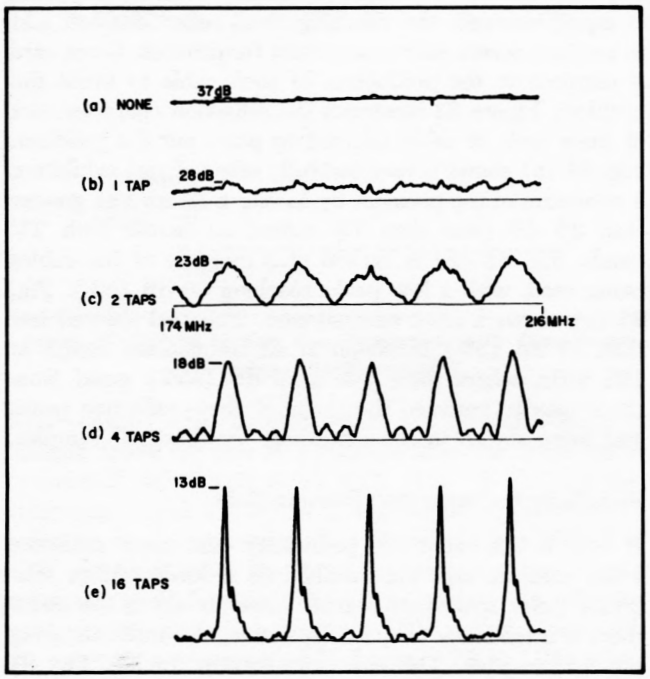


Figure 84. Addition of Reflections, Pressure Taps Spaced at 50' Intervals Along ½" Foam Cable.

TABLE N

Number of Taps	With No Attenuation		Measured	
	Return Loss	Percent Reflection	Return Loss	Percent Reflection
1	28 dB	4%	28 dB	4%
2	22.4 dB	7.7%	23 dB	7%
4	17.5 dB	13.3%	18	13%
16	8.3	38.1%	13 dB	22%

With these severe reflection spikes spaced every 8 MHz across the high-band, transmission of the TV signal through the tap to the customer's receiver is distorted. Fig. 85 shows the frequency response through the first and eighth taps, with response variations of more than 2 dB across a single channel. This condition may well lead to ringing and smearing in the reproduced picture.

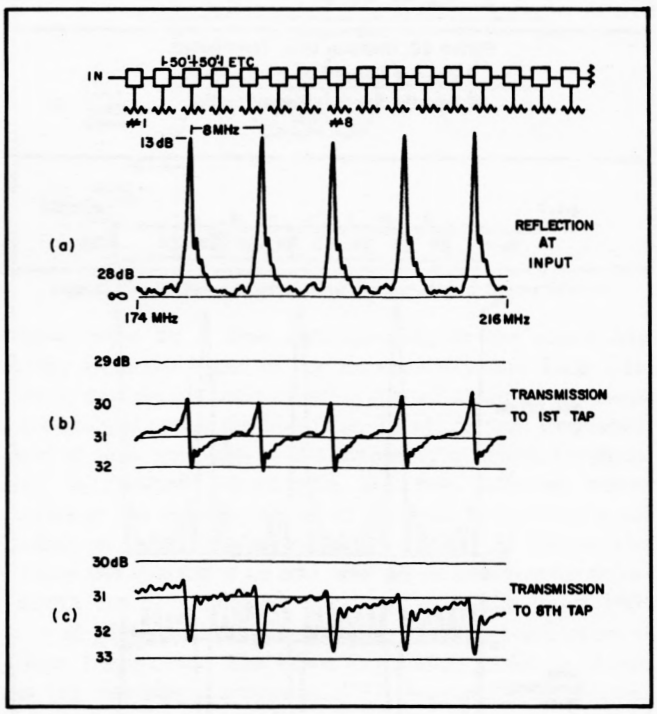


Figure 85. 16 BMT Taps on ½" Feeder, 800' Long, 50 Foot Spacing, High-Band Performance.

The problem is reduced somewhat when taps are installed at irregular intervals so that there is no repetitive pattern. Fig. 86 shows the reflections and responses that resulted when the same 16 taps were installed on the same feeder but spaced completely at random. The reflection pattern is no longer regular and shows reduced amplitude. Transmission variations are improved to a little more than 1 dB in the worst case. This still represents a situation somewhat short of one that would guarantee excellent picture transmission.

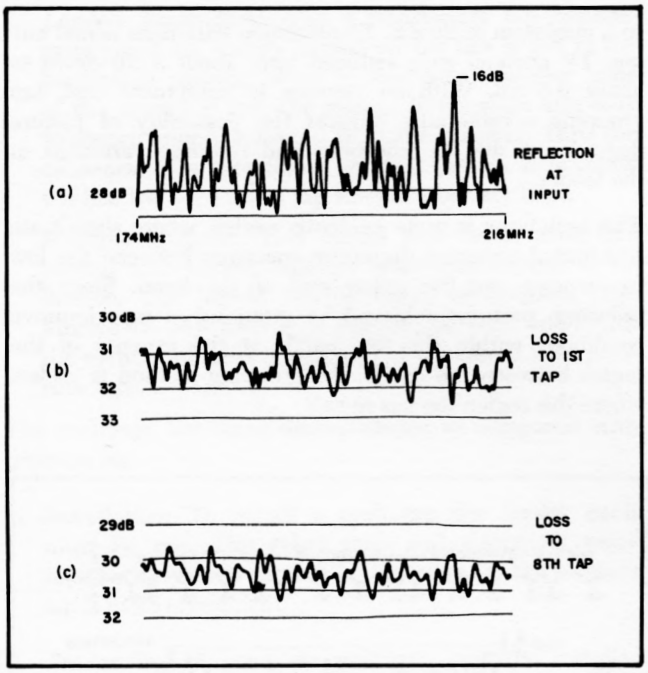


Figure 86. 16 BMT Taps on ½" Feeder 800' Long, Hi-Band Performance. There was one tap in each 50' cable section but spacing was random.

The importance of optimizing the design of the individual tap for minimum reflection is illustrated by Fig. 87. This shows a situation identical with Fig. 86, except that the poorer transformer taps (CMT) were substituted for the better ones (BMT). This increases the peak reflection from 16 dB (16%) to 11 dB (28%), and increases the variation from a little over one dB to more than 3 dB.

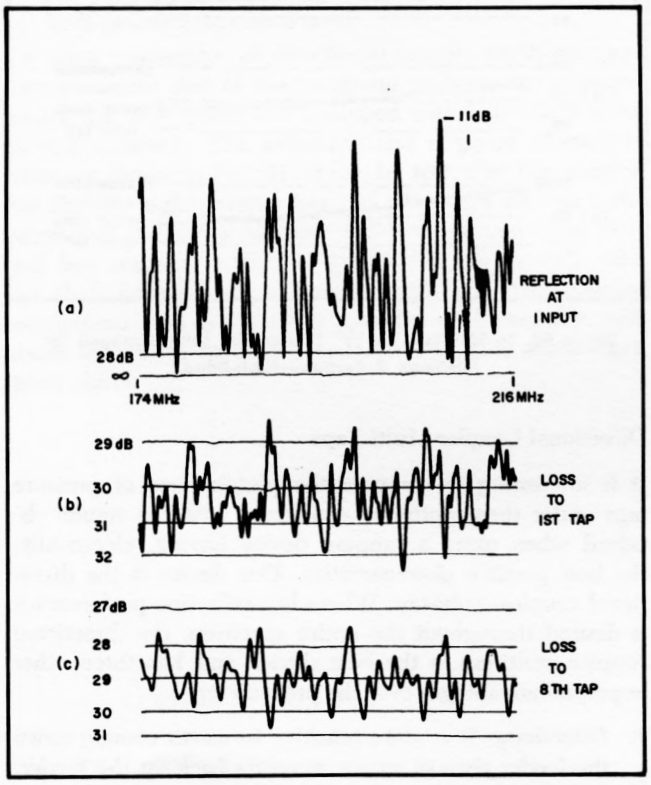


Figure 87. 16 CMT Taps on ½" Feeder 800' Long High Band Performance. There was one tap in each 50' interval but spacing was random.

Using Periodicity to Minimize Reflections

The patterns obtained with simplified reflection conditions (Fig. 81, for example) show narrow peaks with relatively broad areas between where the reflections were low. This effect can be used to reduce reflections in the TV bands by installing taps in periodic arrays with peaks outside of these bands. If the spacing between taps is made 36 inches (for foam-insulated cable) the reflection spike will be at 135 MHz, where this spacing is one-half wavelength and where the reflection does no harm. At 67 and at 201 MHz, where the spacing is one-quarter and three-quarters of a wavelength respectively, the reflections from successive taps will cancel, causing a minimum effect for the TV channels between 54 and 88 and between 174 and 216 MHz.

Fig. 88 illustrates this. Fig. 88 (a) shows a plot of reflection vs. frequency for a single transformer tap (BMT25). It reaches a maximum of close to 28 dB (over 4%) at 216 MHz. When two of these taps are attached to the line 36 inches apart, their reflections cancel at the center of the low band and the center of the high band, as illustrated in Fig. 88 (b). The net effect is that the two taps cause somewhat less reflection than one! An even more dramatic effect is obtained when three taps, Fig. 88 (c)

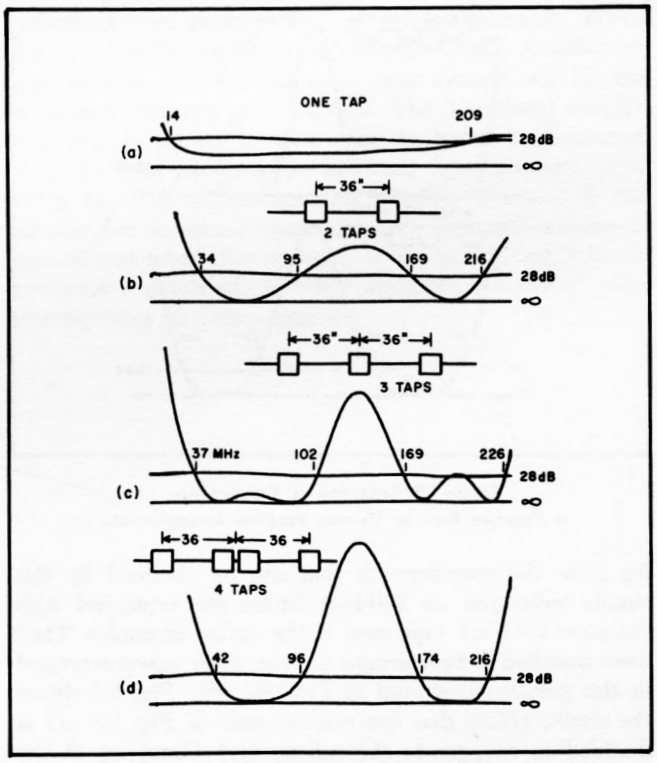


Figure 88. Reflection vs. Frequency— BMT Pressure Taps on ½" Cable.

and four taps, Fig. 88 (d), are connected. Whereas four of these taps could cause as low as 16 dB return loss (16% reflection) if they were installed so that their reflections would add in phase, by scientific grouping they can be made to give less reflection within the TV bands than one tap alone.

When four taps are to be installed at a given location, a fairly common situation in a CATV system, several arrangements are possible. Fig. 89 shows the reflection plots for some of them. The arrangement shown in Fig. 89 (a) probably is the physically most convenient, in that the installer has to reach out only 18″ to either side of the pole. The electrical performance, however, is poor, showing excessive reflection on channels 6, 7 and 13. Either of the other arrangements shown is good; the one shown in Fig. 89 (c) with taps close together at the center, and the other two spaced 36″ on either side, seems to be the best from both the electrical and the mechanical point of view.

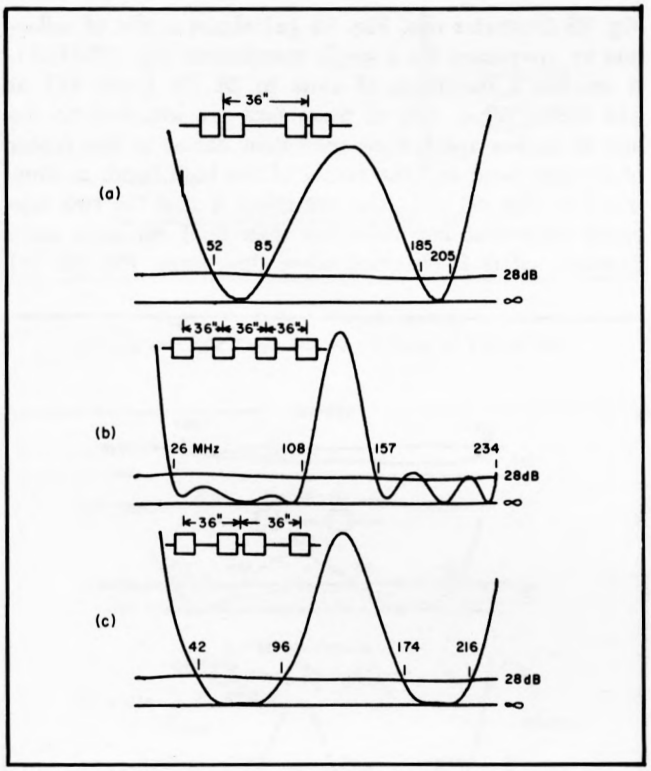


**Figure 89. Reflection vs. Frequency—
4 Pressure Taps in Various Possible Arrangements.**

To show the improvement that can be obtained by this simple technique, an 800-foot feeder was equipped with the same 16 BMT taps used in the earlier examples. They were installed in four groups of four, each group arranged in the pattern illustrated in Fig. 88 (d). Fig. 90 shows the result. (Note that the vertical scale of Fig. 90 (a) is doubled to exaggerate the reflections.) Grouping of the taps in this way increased the feeder return loss as compared with the conditions of Fig. 86 from as low as 16 dB to a minimum of 24 dB. Transmission variations across any one TV channel were reduced from about 2 dB down to about 0.5 dB. With no increase in equipment cost, tap grouping substantially reduces the possibility of picture degradation due to reflections and response variations in the feeder.

This technique is quite evidently useless where signals are distributed covering the entire spectrum between the low frequencies and the upper end of the band. Since the reflection patterns achieved by grouping of taps improve conditions within the two bands at the expense of the region between the bands, the grouping method is useless where this region too has signals.

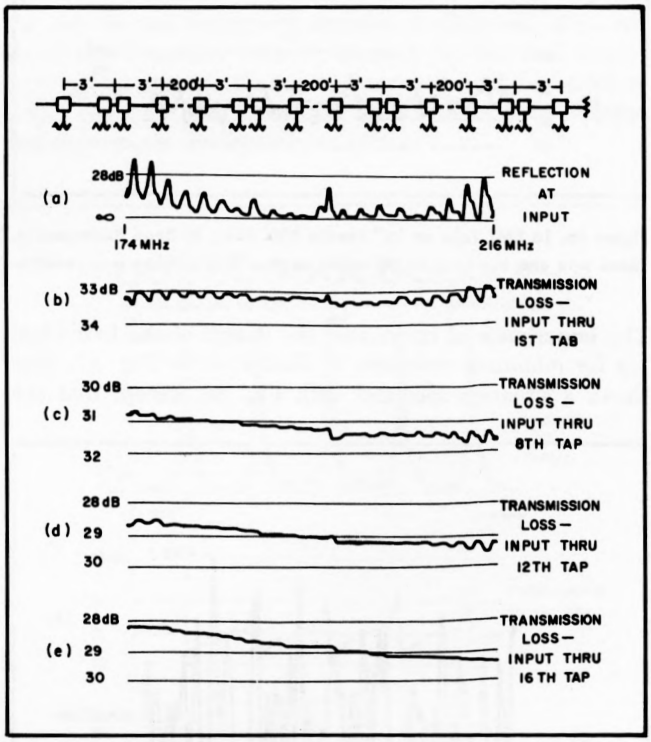


Figure 90. 16 BMT Taps on ½″ Feeder 800′ Long, Grouped for Minimum Reflection—High-Band.

Directional Coupler Multi-Taps

It is interesting to compare the performance of pressure taps under these optimum conditions with the results obtained when using a tapping device having, electrically, the best possible characteristics. This device is the directional coupler multi-tap. Where low-reflection performance is desired throughout the entire spectrum, the directional coupler multi-tap is the best device and has three other important advantages over the pressure tap:

1. *Directivity:* It is more sensitive to waves coming down the feeder than to waves traveling back up the feeder, and thus discriminates against reflections or spurious signals coming from taps or receivers further down the line.

2. *Lossless Backmatch:* With a transformer tap approximately half the energy tapped off the line is lost in the backmatch resistor. With a directional coupler none of this energy is lost, the reverse termination acts only to absorb energy reflected from the receiver. Thus the efficiency of a directional coupler (which determines the line loss for a given tap loss) can be very high.

3. *Multiple Outputs:* This means that fewer units are needed with correspondingly fewer possibilities of reflection. The Jerrold Starline series of couplers (e.g. Models DCM) have four outputs, so only one-fourth the number of units is required as compared with pressure taps.

The multi-tap has three disadvantages as compared with pressure taps:

1. *Installation:* To install a multi-tap the feeder cable must be cut. This takes time and interrupts transmission in systems already in operation, so the pressure tap is more convenient.

2. *Pre-loading:* A complete multi-tap must be installed even if only one house drop cable is to be connected initially; thus the use of multi-taps requires more advance planning and investment.

3. *House-drops:* Although the multi-tap is usually located at a point on the feeder cable where the average house-drop can be kept as short as practical, some of the house drop cables will be longer than they would be if pressure taps were used.

To allow comparison of directional coupler multi-tap performance with that of the foregoing pressure tap arrangements, the 800′ feeder was equipped with four DCM units at 200′ intervals. The reflection and response characteristics are shown in Fig. 91. It can be seen that the coupler has slightly higher return loss (28 dB vs. 24 dB) as compared with the best arrangement of pressure taps (Fig. 90) and less response variation (about 0.3 dB vs. 0.5 dB) but their performance is quite comparable. The coupler requires no care in regard to spacing, works equally well across the entire spectrum, and has the other advantages listed above.

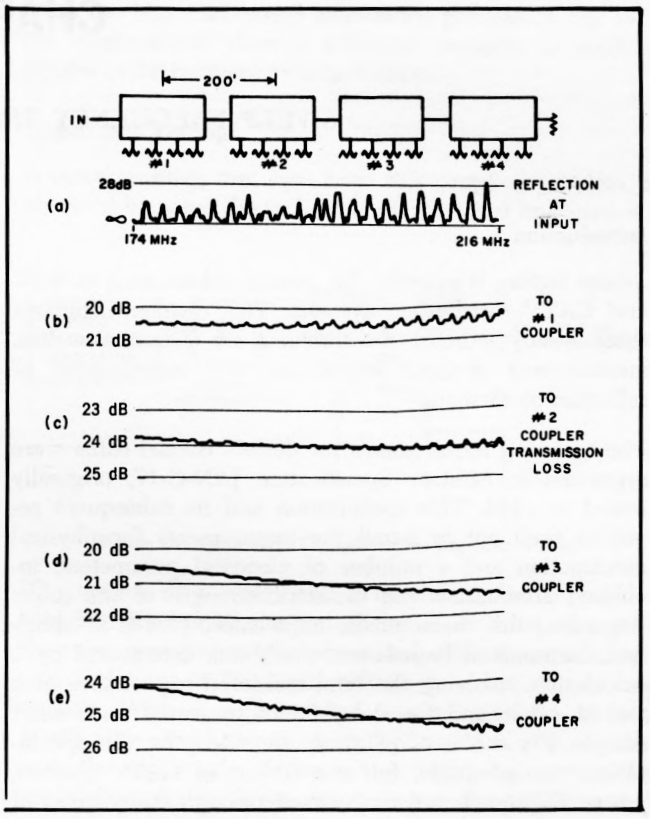


Figure 91. Four DCM Multitaps on ½" Feeder 800' Long Hi-Band Performance.

Summary

This chapter has presented a technique for minimizing the reflections from pressure taps by careful grouping. While the best results are obtained with the better transformer type of taps (BMT), the same improvement will be experienced with any pressure taps. The directional coupler multi-tap is shown to have slightly better performance than the best that can be obtained from pressure taps. With its other advantages this suggests the use of the coupler for situations where the very best performance is desired and where the necessity of cutting the cable is not too great a deterrent; in other situations the use of pressure taps may be quite adequate.

CHAPTER X

SWEEP FREQUENCY TESTING OF COAXIAL CABLE

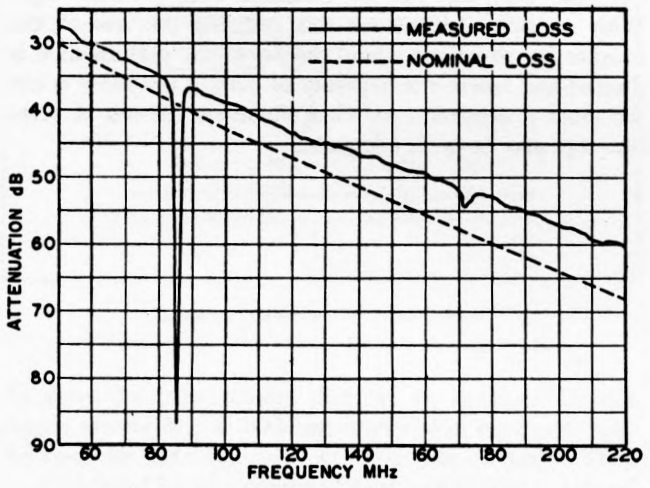
Introduction

Sweep testing is essential for coaxial cables used in ETV and CATV distribution systems. This chapter compares three basic methods: measurement of transmission loss, measurement of input impedance, and measurement of reflection coefficient.

The technical requirements for flexible coaxial cable were organized in Military Specification JAN-C-17, originally issued in 1944. This specification and its subsequent revisions spell out in detail the requirements for physical construction and a number of electrical parameters, including attenuation and dielectric strength of the cable. Regarding the characteristic impedance, JAN-C-17 specified the **nominal impedance** which was determined by a calculation involving the total measured capacitance of a reel of cable, and the delay factor measured on a short sample. For cables of relatively short lengths, this specification was adequate; but the advent of CATV systems, where TV signals are transmitted through many miles of cable, uncovered the need for an additional specification.

The problem first came to light in our organization about twelve years ago when one of our field engineers returned to the laboratory a reel of cable which, he claimed, would not pass TV channel 6.

Figure 92 shows the measured attenuation of this reel of cable, indicating an attenuation spike 50 dB deep at 87 MHz!



Loss versus frequency for 2,000 feet of defective RG11/U cable

Figure 92.

Investigation showed that this effect was due to periodic discontinuities. Something in the manufacture of the cable produced variations in characteristic impedance recurring at precisely spaced intervals throughout the length of the cable. Due to this precise spacing, many reflections, precisely phased at a certain frequency, arrived back at the input end of the cable, causing this severe distortion of the transmission characteristic.

To prevent the recurrence of this problem, a program of factory tests was begun. The original test method involved measuring the transmission loss through each reel of cable over the frequency bands then in use. A reel of cable was rejected if the loss in these bands dipped more than 0.25 dB below the smoothed attenuation characteristic.

After this transmission loss measurement method had been used for several years, it became evident that a more sensitive test was needed. It was found that a measurement of the **input impedance** at each end of a reel of cable gave a more sensitive indication of the existence of periodic reflections. Experience with the impedance measurement method showed two major defects: it was difficult to arrive at an accurate calibration, and the measured deviation was a critical function of cable length. Removing two or three feet from the end of the cable would change the entire pattern.

To overcome these defects, a test method was developed employing a bridge; this method allowed observation and measurement of the **reflections** from the cable end, eliminating uncertainty and allowing easier calibration. This reflection measurement method has been used by a number of cable manufacturers during the past five years and has provided a satisfactory way of controlling periodic defects.

The relative merits of the three methods of sweep frequency cable testing can perhaps best be developed by describing each method in some detail and comparing results.

Transmission Loss Measurement

Figure 93 shows a diagram of the equipment used in the sweep frequency technique for measuring cable loss vs. frequency. A wide-band sweep frequency transmission measuring set is connected alternately to the cable under test and to a variable standard attenuator. This arrangement provides an attenuation reference line on the oscilloscope against which the loss of the cable can be compared.* For accurate measurement it is essential that the cable face a well-matched impedance at each end. 10-dB fixed attenuators are used to establish this condition.

* See the author's article SWEEP MEASUREMENTS MAKING THE TOUGH ONES EASY, in ELECTRONICS, Vol. 36, No. 16, April 19, 1963.

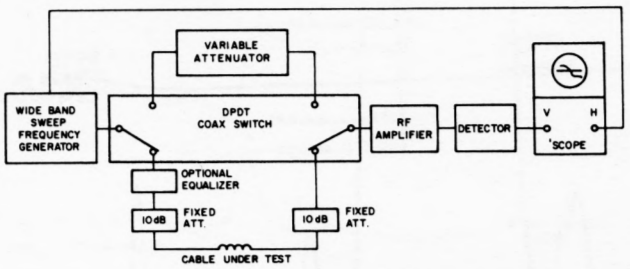


Figure 93. Equipment Connection for Transmission Loss Test.

Figure 94 illustrates the loss characteristic of a particular reel of cable measured with this technique. The frequency range was chosen to include a major defect at 137 MHz. The rapid change in attenuation with frequency makes accurate measurement of the dip at 137 MHz difficult.

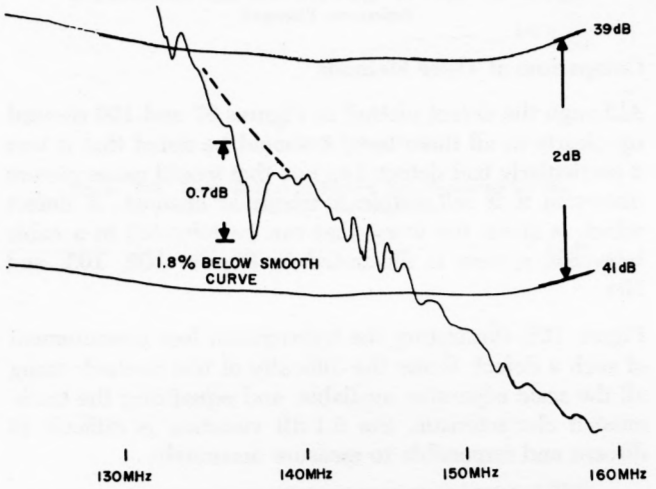


Figure 94. Transmission Loss Measurement, 100' Reel of RG59/U.

The measurement is made easier by inserting an equalizer in series with the cable so that the average loss is flat and the irregularity is more clearly displayed and measured, as shown in Figure 95. One of the defects of the transmission loss measurement method appears on this plot.

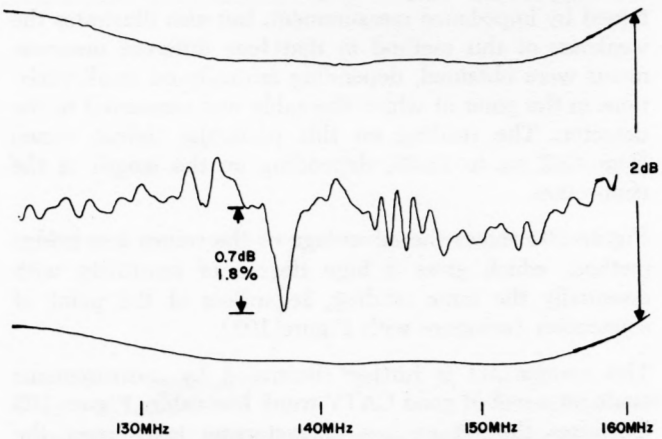


Figure 95. Transmission Loss Measurement 1000' Reel RG59/U Equalized.

With the high end-to-end attenuation present on this reel, the single shield allowed sufficient coupling to produce ripples in the frequency characteristic.

Impedance Testing

A more sensitive test, free from this coupling problem, is obtained by using the technique diagrammed in Figure 96.

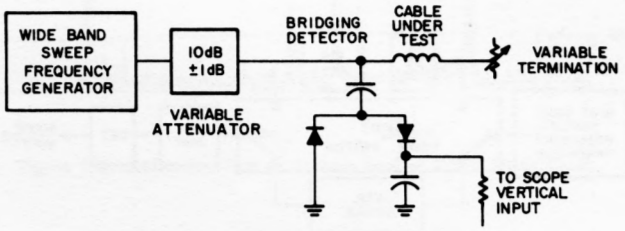


Figure 96. Equipment Connection for Impedance Test.

The output of a wide-band generator is fed through a bridging detector to one end of the cable under test, with the other end accurately terminated. The detector measures variations in the input voltage as a function of frequency. With a well-matched source (assured by the 10-dB attenuator) the input voltage varies almost directly with the magnitude of the cable's input impedance. An impedance plot made by this technique for the same reel of cable is illustrated in Figure 97 (compare with Figure 95).

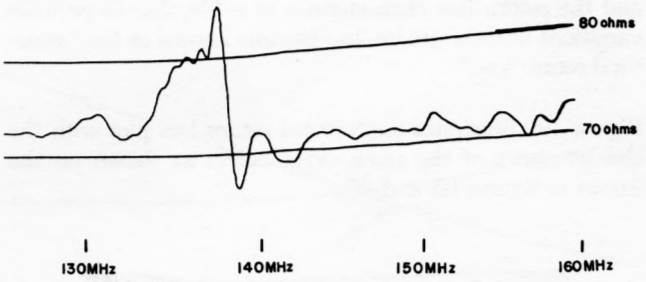


Figure 97. Impedance Test on 1000' Sample of RG59/U.

Calibration was obtained by substituting a precise 75-ohm terminator for the cable end and varying the attenuator above and below 10 dB by an amount corresponding to the indicated impedance levels.

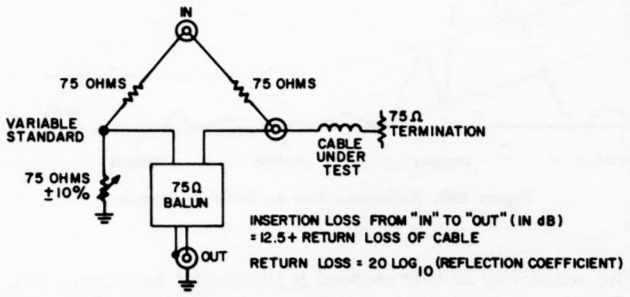


Figure 98. Variable Bridge for Cable Reflection Testing.

Structural Return Loss Testing

The bridge used for reflection testing is diagrammed in Figure 98. When the variable standard arm of the bridge is adjusted to equal the average characteristic impedance of the cable, the bridge acts as a directional coupler with directivity in excess of 50 dB and a constant insertion loss of about 12.5 dB. The bridge is connected into a test system, as shown in Figure 99.

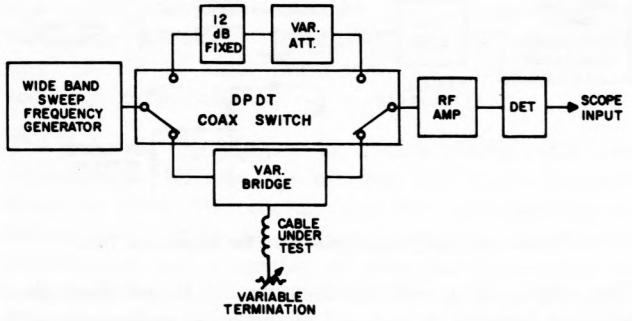


Figure 99. Equipment Connection for Reflection Test.

The variable attenuator generates a reference trace which is set to cross the cable trace at peaks of the reflection characteristic. Since the measurement is made in dBs, the results are most conveniently expressed in these terms. The reflection coefficient expressed in dB is the "return loss," and the return loss characteristic of cable, due to periodic variations in its structure, has become known as the "structural return loss."

Figure 100 illustrates a structural return loss plot with the characteristics of the same cable defect as shown on the curves in figures 95 and 97.

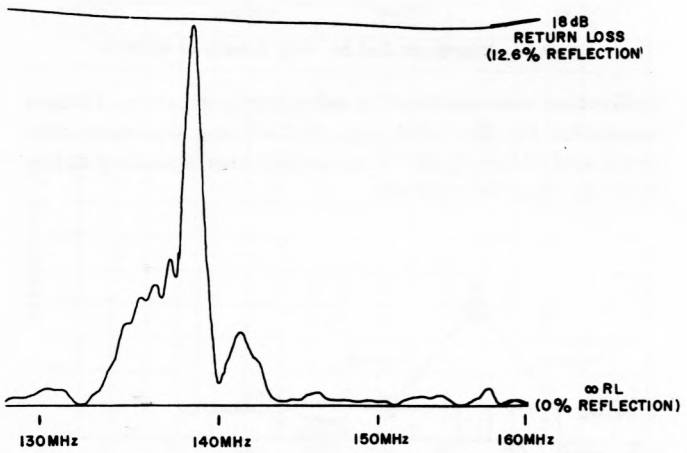


Figure 100. Reflection Test on RG59/U Sample.

The sensitivity of this method is illustrated by Figure 101, which is similar to Figure 100, but shows a 15-dB increase in sensitivity. Return loss variations as low as 50 dB (0.3% reflection) can be clearly displayed.

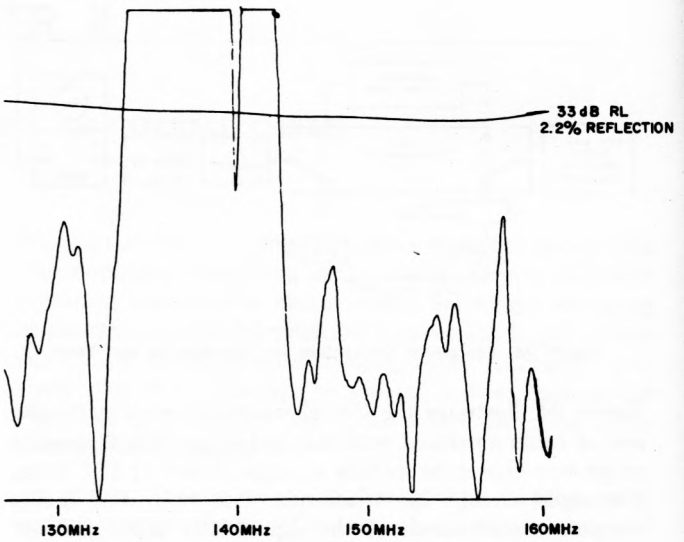


Figure 101. Same as Figure 100 with Gain Increased and Reference Changed.

Comparison of Three Methods

Although the defect plotted in Figures 97 and 100 showed up clearly in all three tests, it should be noted that it was a particularly bad defect, i.e., one that would cause picture distortion if it fell within a television channel. A defect which is about the worst that can be tolerated in a cable television system is illustrated in Figures 102, 103, and 104.

Figure 102, illustrating the transmission loss measurement of such a defect, shows the difficulty of this method: using all the scale expansion available, and equalizing the transmission characteristic, the 0.1-dB variation is difficult to discern and impossible to measure accurately.

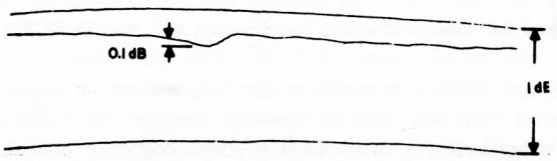


Figure 102. Measurement of a Cable Defect by Transmission Loss Method.

Figure 103 shows a great improvement in sensitivity obtained by impedance measurement, but also illustrates the weakness of this method in that four different measurements were obtained, depending critically on small variations in the point at which the cable was connected to the detector. The reading on this particular defect varied from 4.4% up to 12.3%, depending on the length of the connection.

Figure 104 shows the advantage of the return loss bridge method, which gives a high degree of sensitivity with essentially the same reading, regardless of the point of connection (compare with Figure 103).

This comparison is further illustrated by measurements made on a reel of good CATV trunk line cable. Figure 105 illustrates the return loss characteristic taken over the entire TV spectrum, showing excellent structural return loss characteristics.

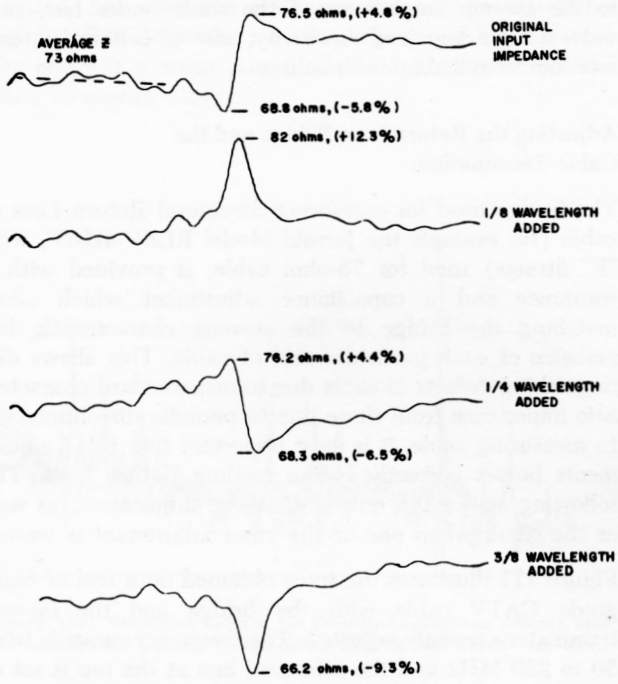


Figure 103. Same Defect as Figure 101 Measured by the Impedance Test Method.

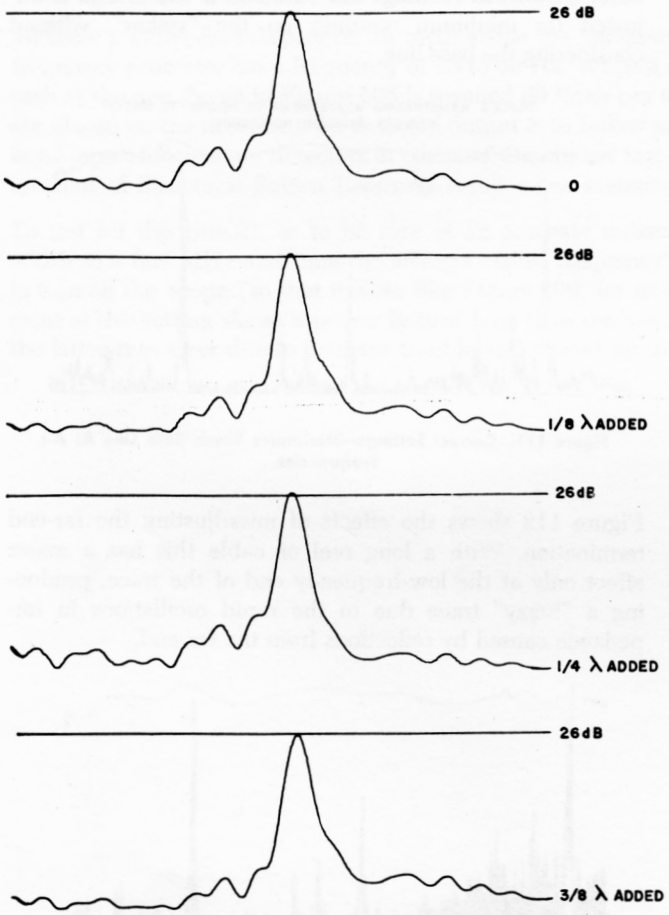


Figure 104. Same Defect as Figures 101 and 103 Measured by the Reflection Test Method.

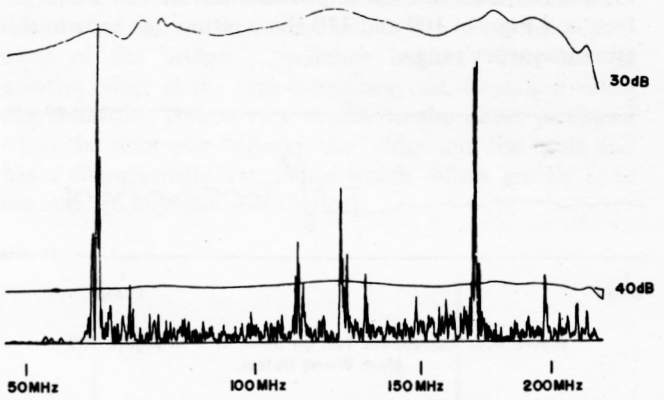


Figure 105. Reflection Test on Sample Reel of CATV Trunk Cable.

Figures 106 and 107 show transmission loss measurements near the worst defect. Note that the transmission loss variation at this point can hardly be seen. None of the variations below this level could be seen or measured by this method.

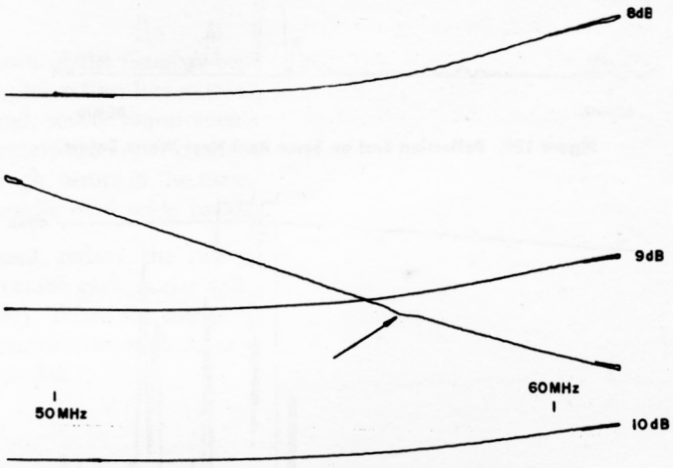


Figure 106. Transmission Loss Test on Same Reel as Figure 105 Near Worst Defect.

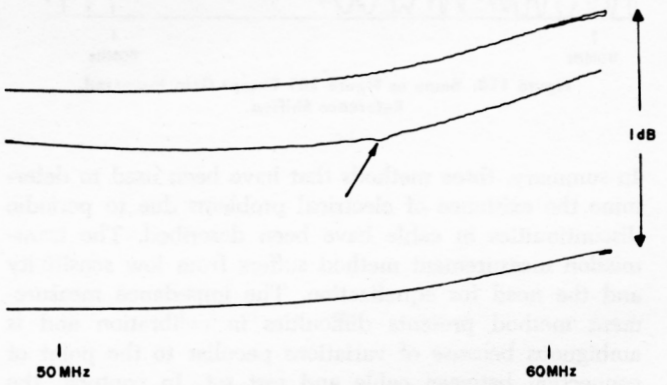


Figure 107. Same as Figure 106 Except Transmission Line Equalized.

Figure 108 illustrates an impedance test of this worst defect, and Figures 109 and 110 show return loss tests in this same frequency range.

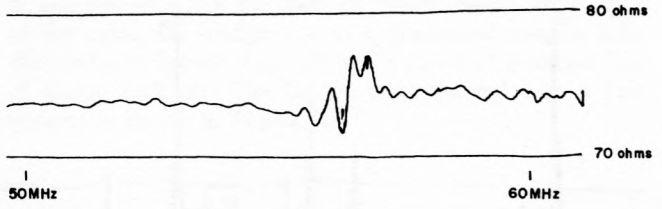


Figure 108. Impedance Test on Same Reel as Figure 105 Near Worst Defect.

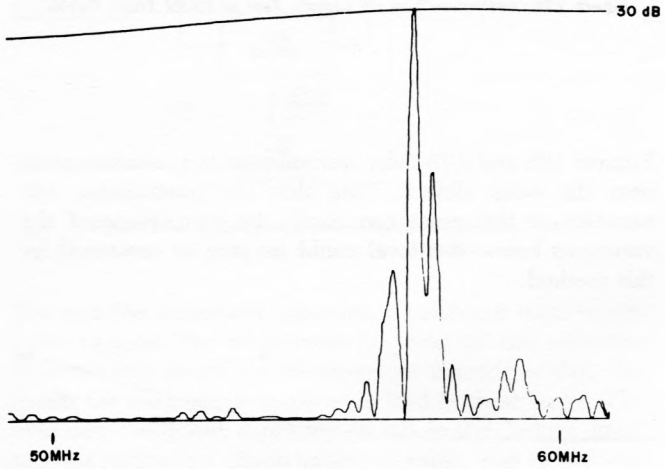


Figure 109. Reflection Test on Same Reel Near Worst Defect.

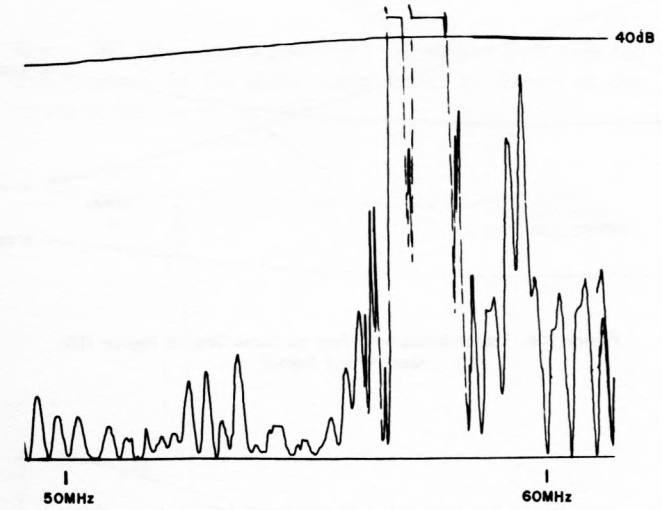


Figure 110. Same as Figure 109 Except Gain Increased, Reference Shifted.

In summary, three methods that have been used to determine the existence of electrical problems due to periodic discontinuities in cable have been described. The transmission measurement method suffers from low sensitivity and the need for equalization. The impedance measurement method presents difficulties in calibration and is ambiguous because of variations peculiar to the point of connection between cable and test set. In contrast, the reflection test method, using a return loss bridge adjusted to the average impedance of the cable under test, provides a high degree of sensitivity, ease of calibration, and freedom from ambiguous readings.

Adjusting the Return Loss Bridge and the Cable Termination:

The bridge used for measuring Structural Return Loss of cable (for example the Jerrold Model RLBV-4H-7F, with "F" fittings) used for 75-ohm cable, is provided with a resistance and a capacitance adjustment which allow matching the bridge to the average characteristic impedance of each particular reel of cable. This allows distinguishing defects in cable due to non-standard characteristic impedance from those due to periodic discontinuities. In measuring cable, it is most important that these adjustments be set correctly before reading Return Loss. The following shows the result of correct adjustment, as well as the result when one or the other adjustment is wrong.

Figure 111 illustrates the trace obtained on a reel of high-grade CATV cable with the bridge and the far-end terminator correctly adjusted. The frequency range is from 50 to 220 MHz and the reference line at the top is set at 30 dB return loss. It is essential to set the bridge so that the minimums in the trace touch the base line as they do here. Erroneous readings are obtained if the bridge is adjusted for minimum readings on the "spikes", without considering the base line.

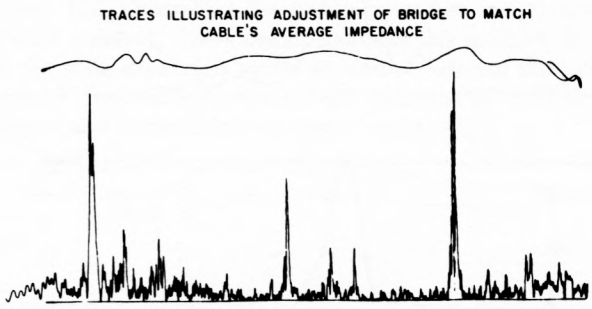


Figure 111. Correct Settings—Minimums Reach Base Line At All Frequencies.

Figure 112 shows the effects of misadjusting the far-end termination. With a long reel of cable this has a major effect only at the low-frequency end of the trace, producing a "fuzzy" trace due to the rapid oscillations in impedance caused by reflections from the far end.

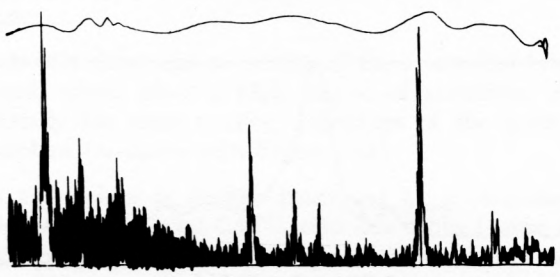


Figure 112. Termination Misadjusted—Makes Trace Fuzzy, Especially At Low End.

Figure 113 shows a trace with the far end correctly terminated, but with the resistance balance on the bidge slightly offset from the average impedance for this reel. The effect is a trace raised off the base line across the entire frequency range.

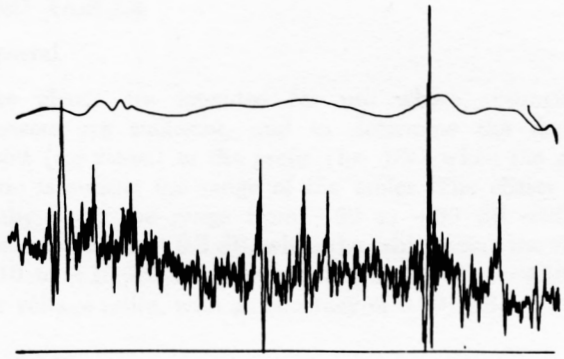


Figure 113. Resistance Balance Set Wrong—Capacitance Balance and Termination Set Correct. (NOTE: Minimums Do Not Reach Base Line.)

Figure 114 shows a trace with far-end termination and resistance balance set correctly, but with a slight misadjustment of the bridge capacitance balance. This has its greatest effect at the high-frequency end, causing a rising characteristic. This is very similar to the effect produced when the connector between the bridge and the cable end has a characteristic impedance which differs greatly from the average impedance of the reel.

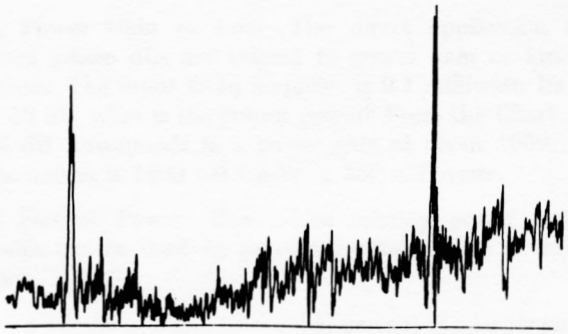


Figure 114. Capacitance Balance Set Wrong, Curve Tips Up At High End. This Can Also Be Caused By Bad Connection Between Cable and Bridge.

Note: Error Due to Detector Envelope Response

To show a flicker-free display on an oscilloscope the horizontal scan of the usual sweep-frequency generator has a frequency of 25 to 60 Hz. When a complex return loss pattern, such as the one shown in Figure 105 is scanned 60 times per second, severe requirements are placed on the detector if its detected output is to follow accurately the rapid changes in r-f input. Since many detectors in common use are not fast enough, errors in the measurement of Structural Return Loss may result when scanning rapidly over wide bands.

To test for this trouble, or to be sure of an accurate measurement, reduce the sweep-width to a few MHz and tune the sweep's center frequency to center each major spike in turn on the 'scope (so that it looks like Figure 109, for example). When the measurement at this setting shows a poorer Return Loss than the measurement with wide sweep, the latter is in error due to detector trouble and should be disregarded.

CHAPTER XI

CHARTS AND TABLES

INSTRUCTIONS ON THE USE OF CHARTS AND TABLES

General

The charts are intended for use where approximate answers are sufficient, and to determine the decimal point (for ratios) or the prefix (for dBs) when the given ratio is outside the range of the tables. The charts generally cover the range from −60 to +60 dB with an accuracy of about 0.5 dB, while the tables cover the range −10 to +10 dB for power ratios, and −20 to +20 dB for voltage ratios, with an accuracy of 0.001 dB.

Use of Charts

Each chart may be entered either horizontally (when you know the **ratio**) or vertically (when you know the **dBs**). For example, assume you know the power ratio is 4200 and want the corresponding dBs. Use chart P2, covering power ratios between 1 and 1,000,000. Notice that 4200 shows on the right-hand scale, and following the indication of the arrows, the bottom scale is used with this for dBs. Moving across the 4200 line you will see that it intersects the slanting line above 36.5 dB on the bottom scale. So **36.5 dB** is the answer.

As an example of the reverse conversion, suppose you are given −14 dB, to find the power ratio. Use chart Pl. −14 dB occurs on the bottom scale, and according to the arrows the left-hand scale goes with this. The 14 dB line intersects the slanting line at a power ratio of **0.039**, the answer.

Use of Tables

Each table is always entered from the left. Find the first two significant figures of the given number in the left-hand column, then locate the answer under the column headed by the third significant figure. As an example, assume a given power ration of 4250. Use table P7 (power ratios between 1.0 and 10) to find the dBs corresponding to 4.25. Find 4.2 in the left-hand column, follow this line to the right to find the answer **6.284** dB in the 0.05 column. From the chart, as described above, 36.5 dB corresponds approximately with a power ratio of 4200, so the accurate dB number for a ratio of 4250 is found by adding 30 to that found for 4.25, giving **36.284** dB.

When the given number is in dB, another table is used. Given −14.15, for example, the approximate ratio from chart Pl, is 0.039 (as illustrated above). To find the accurate ratio, look up −4.15 dB in table P6. On the 4.10 line under the 0.05 column find a ratio of 0.3846. Moving the decimal point to agree with the chart answer gives the accurate power ratio **0.03846.**

APPLICATIONS OF THE POWER vs. dB CHARTS AND TABLES

1. **Power Gain or Loss** The direct application is to cases where dBs are related to power gain or loss. *Example:* The input to an amplifier is 0.1 milliwatt. Its gain is 32 dB, what is the output power? From the Chart (P2) 32 dB corresponds to a power gain of about 1600. Thus the output is 1600 x 0.1 mW or 160 milliwatts.

2. **Percent Power** The tables relating power ratio to −dBs can be used for percent by making use of the fact that:

a smaller power, expressed in percent of a larger one

$$= 100 \text{ x the power ratio } \left(\frac{\text{smaller power}}{\text{larger power}}\right)$$

Example: When the ratio of two powers is 0.119, the smaller is 11.9% of the larger (11.9 = 100 × 0.119).

Example: The loss of a certain directional coupler from input to tap is 17.2 dB. What percent of the input power reaches the tap? From chart P1 and table P6 relating power ratio and − dB, −17.2 dB corresponds to a power ratio of 0.0190. So the power reaching the tap is 1.9% (0.019 × 100) of the input.

3. **Conversion of Power to dBm** The dBm (abbreviation for "dB above one milliwatt") is commonly used to express power levels in electronics (other than in CATV). It is defined by: Power level in dBm = dBs corresponding to the ratio of the given power to the standard power of 1 milliwatt.

To find dBm corresponding to a given power:

a. Convert power to milliwatts

b. Consider this as a power ratio, and find dBm in table or chart relating ratio and dB.

Example: Express a power of 7.75 watts in dBm.

a. 7.75 watts is 7750 milliwatts (mW = W × 1000).

b. From Chart P2, a power ratio of 7750 corresponds to 38.9 dB. So 7.75 watts corresponds to +38.9 dBm.

4. **Conversion of dBm to Power** The power ratio corresponding to the given dBm is the power in milliwatts.

Example: What power is represented by −16.2 dBm?

From Chart P1, −16.2 dB corresponds to a ratio of 0.024. So the answer is **0.024** mW.

5. **Relation between dBm and dBmV.** Since dBm and dBmV both express power levels in dBs, they are related by a constant factor. To find this factor, we have to calculate first the power corresponding to 1 millivolt across 75 ohms:

$$\text{Power} = \frac{E^2}{R} = \frac{\frac{1}{(1000)^2}}{75} = \frac{1}{75 \times 10^6} \text{ watts;}$$

Then we divide this into one milliwatt to find the power ratio:

$$\text{Power Ratio} = \frac{\frac{1}{1000}}{\frac{1}{75 \times 10^6}} = \frac{75 \times 10^6}{1000} = \mathbf{75{,}000.}$$

From Chart P2 and Table P7, we find that the number of dBs corresponding to a power ratio of 75,000 is **48.75 dB.**

From this follow the rules:

a. To convert dBmV to dBm: subtract 48.75 dB.

b. To convert dBm to dBmV: add 48.75 dB.

6. **Noise Factor and Noise Figure.** In some noise problems it is necessary to find the Noise Factor of a device. This is simply the power ratio corresponding to the Noise Figure. As Noise Figure is expressed in dB, and Noise Factor is a power ratio, we can use the Power vs. dB charts and tables to find one when the other is known.

Example: An amplifier has a measured noise figure of 8.3 dB; what is the noise factor?

From table P8 we find the noise factor is **6.761.**

7. **System Noise Calculations**—when one amplifier follows another with no attentuation between them. When the output of one amplifier is connected directly to the input of another, the noise factor of the combination is found from the formula:

$$f_{1,2} = f_1 + \frac{f_2 - 1}{G_1}$$

where: f_1 is the noise factor of the first amplifier,
f_2 is the noise factor of the second amplifier,
G_1 is the power gain of the first amplifier.

This formula applies only to noise factors and power gain, so when noise figures and dB gain are given, they must be converted to the corresponding ratios before the formula can be used.

Example: An amplifier with a noise figure F_1 of 6.3 dB and gain of 4.5 dB is followed by a second amplifier with a noise figure F_2 of 13.7 dB; what is the noise figure $F_{1,2}$ of the combination?

a. Find the power ratios from chart P2, table P8:

F_1 (power ratio corresponding to 6.3 dB) = 4.27
F_2 (power ratio corresponding to 13.7 dB) = 23.44
G_1 (power ratio corresponding to 4.5 dB) = 2.82

b. Find the combined noise factor $f_{1,2}$ by applying the formula:

$$f_{1,2} = 4.27 + \frac{23.44 - 1}{2.82} = 4.27 + \frac{22.44}{2.82} =$$

$$= 4.27 + 7.96 = \mathbf{12.23}$$

c. To find the combined noise figure we convert this ratio to dBs. Using chart P2, table P7, we find a power ratio of 12.33 corresponds to **10.9 dB.**

8. **Power Addition** A problem that occurs in studying noise in CATV systems is to find the power level corresponding to the sum of the powers represented by two given levels. One way to solve this is to use the Power vs. dB tables:

Example: The noise at a certain point in a system is due to two components, one at +7.31 dBmV, the other at +12.73 dBmV. What is the level of the total noise?

a. Find the power ratios (to 0 dBmV) corresponding to the given levels from Chart P2, Table P8.

b. Add the ratios to find the power ratio of the total.

c. Find corresponding dBmV.

In this case: +7.31 dB corresponds to a power ratio of 5.383, and +12.73 dB corresponds to a power ratio of 18.75. The sum of the power ratios is 24.13, and (from Chart P2, Table P7) the corresponding total noise level is **13.82 dBmV.**

A somewhat faster way to solve problems involving power addition, is to use the chart P3 or table P9 relating the difference between two dBmV levels to the dB to be added to the larger to find the level corresponding to the power sum.

Example: Assume the same problem as above, where we were given two noise contributions of +7.31 dBmV and +12.73 dBmV to find the level corresponding to the total noise. The dB difference is 12.73 − 7.31 = 5.52 dB. On Chart P3, opposite 5:5 dB difference, we find 1.1 dB. Adding 1.1 to 12.73, we obtain the answer: **13.8** dBmV (compare with solution above).

When negative levels are involved, remember that the higher level is the one with the smaller number of negative dBs: To find the level corresponding to the power sum of −17 and −20 dBmV, opposite the difference (3 dB) on chart P3, find 1.8 dB. Add this to the higher level, which is −17 dBmV: −17 + 1.8 = **−15.2.**

9. **Power Division** Another application of the "power sum" idea allows simplified analysis of splitters and taps in CATV systems. A splitter divides energy between two outgoing cables; a directional coupler or tap diverts a small part of the feeder's energy to the house drop, passing the major part down the feeder. Each of these devices is designed to have as little internal power loss as possible, so their performance can be estimated by assuming that there is no power loss, all of the energy dividing between the output. Figure 115 is a diagram of such a device.

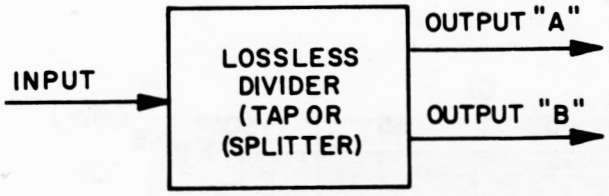


Figure 115.

Assuming no internal loss:

Input Power = Output Power "A" + Output Power "B".

When this relation is established, chart P4 or table P10 can be used to find the loss from input to one output, when the loss from the input to the other output is known.

Example: A directional coupler has 12 dB tap loss; what would the line loss be if the coupler had no internal losses? On chart P4, or in table P10, opposite 12 dB tap loss we find a line loss of **0.28 dB.**

These relations assume no internal loss, but one case with loss can be handled readily. When a non-directional tap includes a resistor to provide back-match of the tap output, the tap output energy divides almost equally between this resistor and the tap output (see Figure 116).

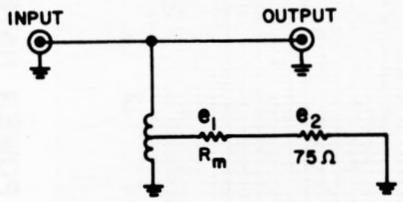


Figure 116.

In this situation the line loss can be found by first subtracting 3 dB from the actual tap loss, and then looking up the corresponding line loss on chart P4.

A 16-dB back-matched tap, for example, would have the same loss (0.22 dB) as a lossless 13-dB tap.

10. **Application of Power-Split Data to Reflection Problems**
When a lossless device having mismatch is introduced between a previously matched source and load (see Figure 117) the power-split curve on chart P4 can be used to find the resulting insertion loss.

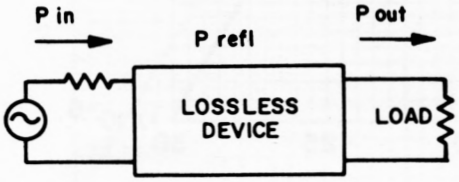


Figure 117.

A commonly used measure of reflection in CATV equipment and cables is the "return loss", the dB ratio of input power to reflected power. When the device is lossless, the sum of the output power and the reflected power must equal the input power. Thus the "power-split" curve can be used to find the insertion loss $\frac{(P_{in})}{(P_{out})}$ when the return loss $\frac{(P_{in})}{(P_{refl})}$ is known.

Example: A filter has the impedance match shown in Figure 118:

What is its insertion loss, if there are no internal losses?

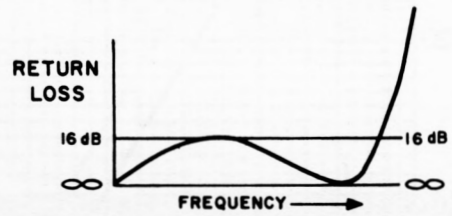


Figure 118.

Loss at minimums, where return loss is infinite, is 0.
Loss at maximums, where return loss is 16 dB, is 0.11 dB (from P4 or P10) so the transmission curve is approximately as shown in Figure 119.

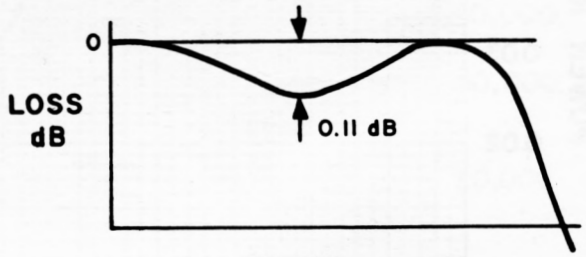


Figure 119.

Example: A cable has the return loss spike shown in Figure 120.

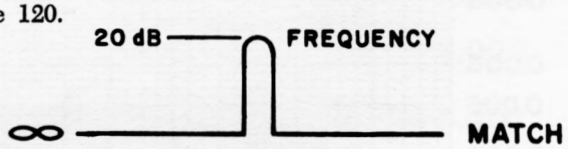


Figure 120.

What insertion loss is caused? (assuming it is due only to the mismatch at the input terminal).

With a 20-dB return loss spike the insertion loss (from P10) is 0.04 dB as shown in Figure 121.

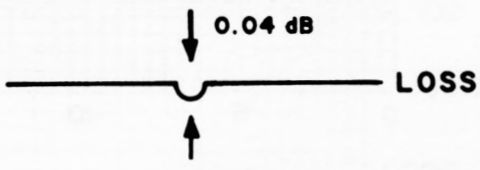


Figure 121.

CHART P1

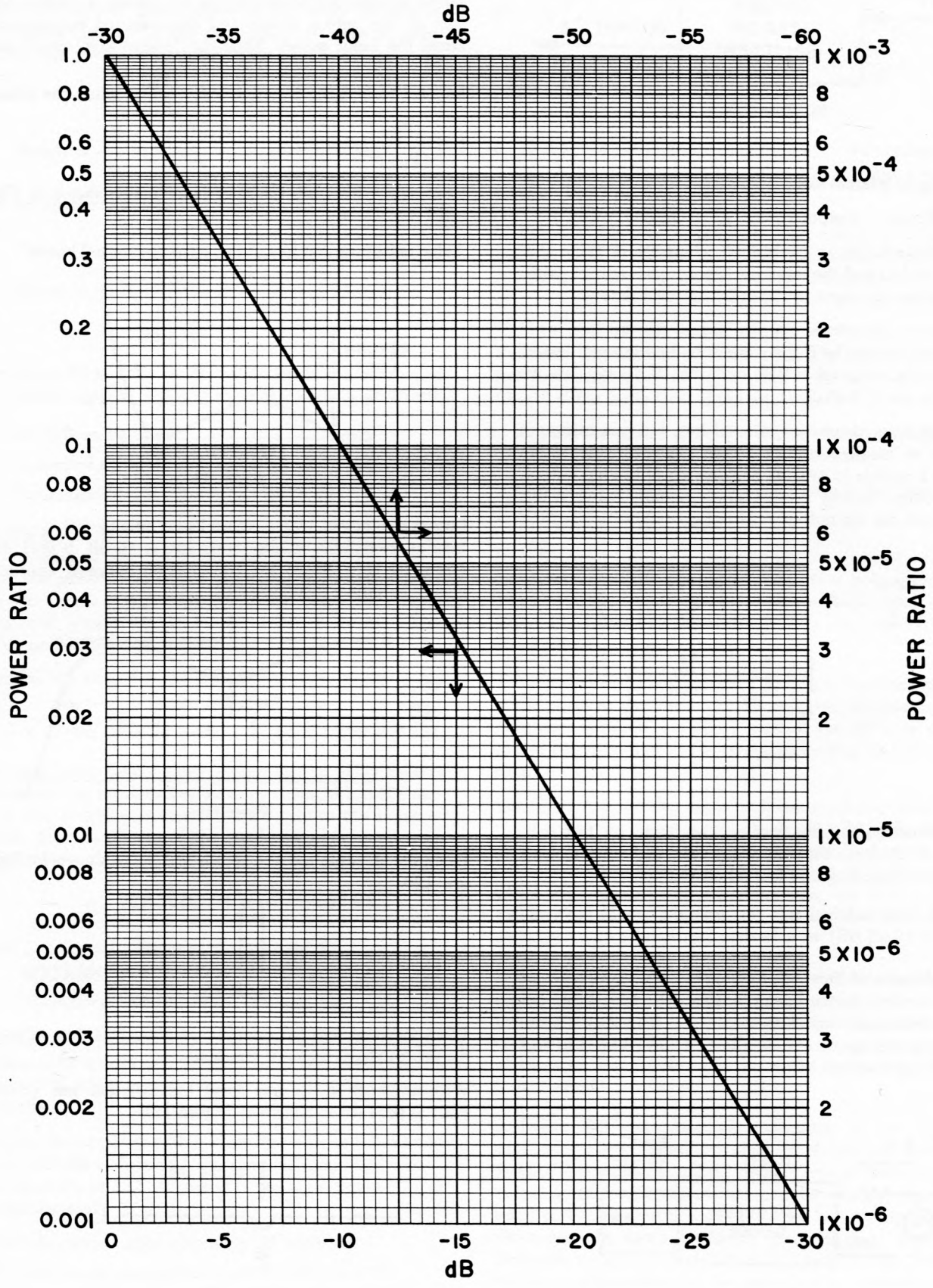

dB
-30
-35
-40
-45
-50
-55
-60
1.0
0.8
0.6
0.5
0.4
0.3
0.2
0.1
0.08
0.06
0.05
0.04
0.03
0.02
0.01
0.008
0.006
0.005
0.004
0.003
0.002
0.001
1 X 10-3
8
6
5 X 10-4
4
3
2
1 X 10-4
8
6
5 X 10-5
4
3
2
1 X 10-5
8
6
5 X 10-6
4
3
2
1 X 10-6
POWER RATIO
POWER RATIO
0
-5
-10
-15
-20
-25
-30
dB

CHART P2

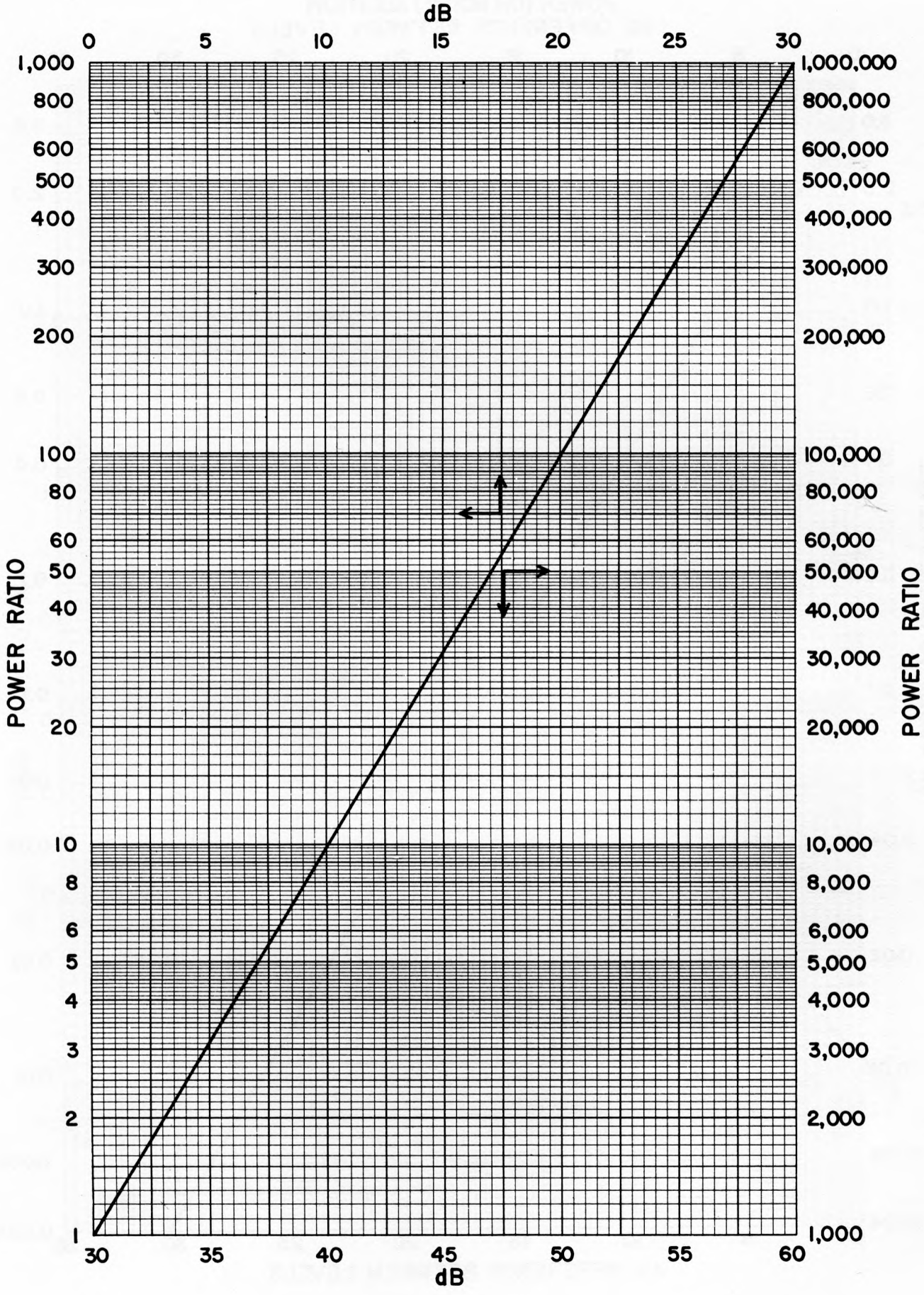

dB
0
5
10
15
20
25
30
1,000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1
POWER RATIO
1,000,000
800,000
600,000
500,000
400,000
300,000
200,000
100,000
80,000
60,000
50,000
40,000
30,000
20,000
10,000
8,000
6,000
5,000
4,000
3,000
2,000
1,000
POWER RATIO
30
35
40
45
50
55
60
dB

CHART P3

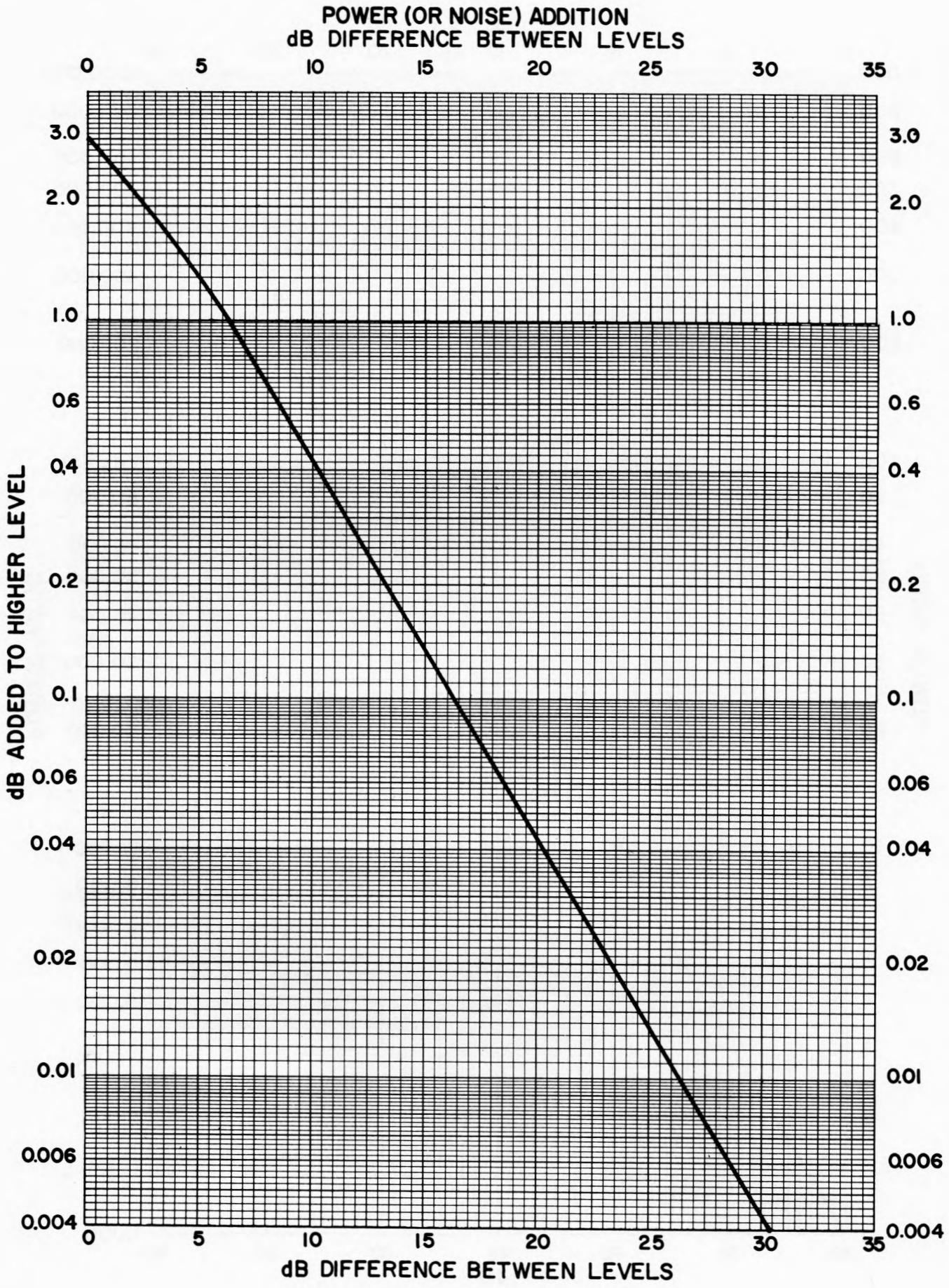

POWER (OR NOISE) ADDITION
dB DIFFERENCE BETWEEN LEVELS
0
5
10
15
20
25
30
35
3.0
2.0
1.0
0.6
0.4
0.2
0.1
0.06
0.04
0.02
0.01
0.006
0.004
dB ADDED TO HIGHER LEVEL
dB DIFFERENCE BETWEEN LEVELS

CHART P4

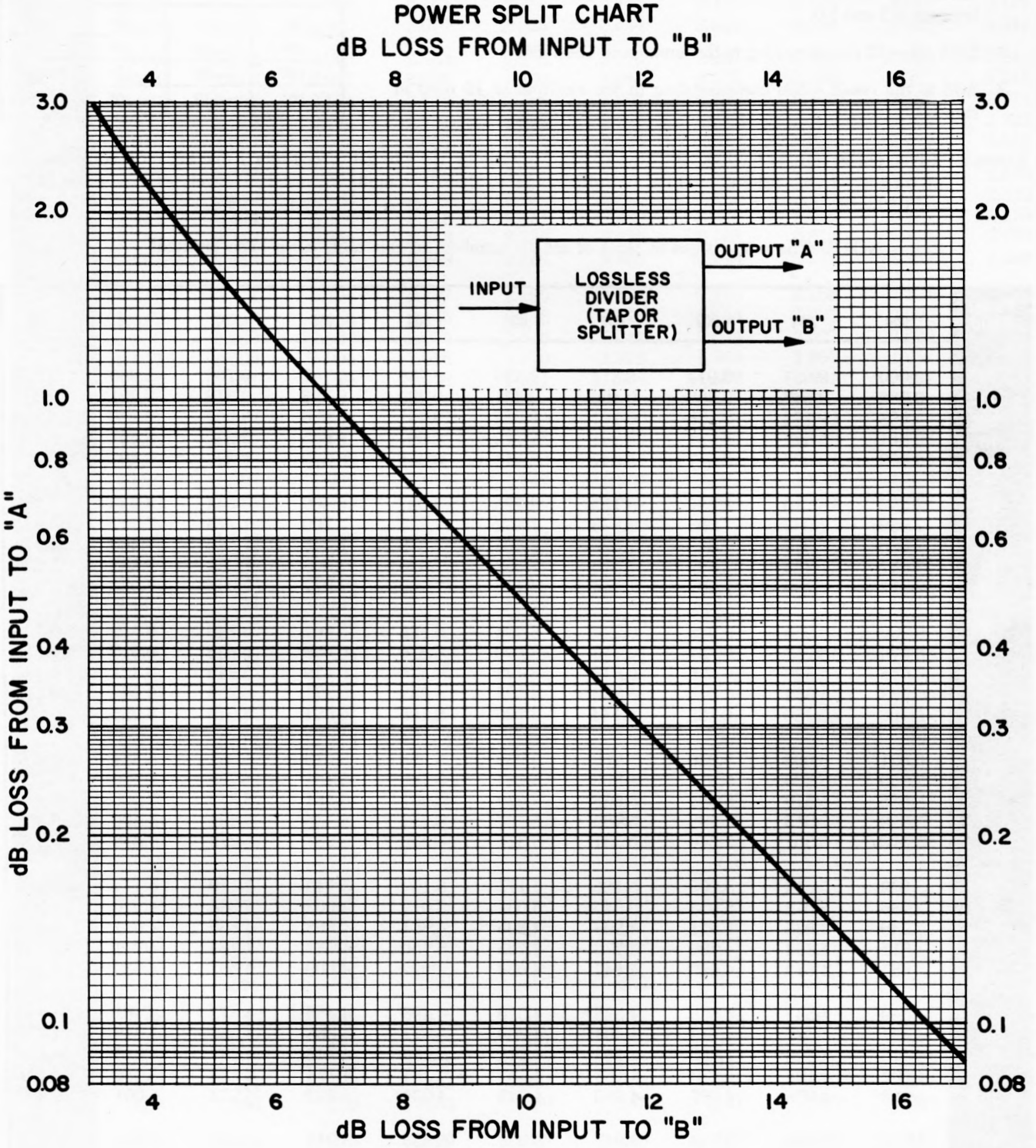

POWER SPLIT CHART
dB LOSS FROM INPUT TO "B"
4
6
8
10
12
14
16
3.0
2.0
1.0
0.8
0.6
0.4
0.3
0.2
0.1
0.08
INPUT
LOSSLESS DIVIDER (TAP OR SPLITTER)
OUTPUT "A"
OUTPUT "B"
dB LOSS FROM INPUT TO "A"
dB LOSS FROM INPUT TO "B"

TABLE P5 GIVEN: POWER RATIO (0.1 to 1.0); FIND −dB (−10 to 0)

For power ratios less than 0.1:

1. Multiply given ratio by a multiple of 10 as required to give a number between 0.1 and 1.0.
2. Look up −dB corresponding to this number in Table P5.
3. Add to the result −dBs corresponding to the multiple of 10 used in step 1.

Multiple of 10	Add −dBs	Multiple of 10	Add −dBs
10	−10	10^5	−50
10^2	−20	10^6	−60
10^3	−30	10^7	−70
10^4	−40	10^8	−80

Example: Given power ratio = 0.0000076 (7.6×10^{-6}). Multiply by 10^{-5} to get 0.76. From Table P5, −dB corresponding to 0.76 is −1.192. Adding −50 dB (corresponding to the 10^{-5} multiplier used) we get −1.192 + (−50) = **−51.192 dB.**

NOTE: The minus signs in front of all dB numbers in this table have been omitted!

Power Ratio	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.10	10.000	9.957	9.914	9.872	9.830	9.788	9.747	9.706	9.666	9.626
.11	9.586	9.547	9.508	9.469	9.431	9.393	9.355	9.318	9.281	9.245
.12	9.208	9.172	9.136	9.101	9.066	9.031	8.996	8.962	8.928	8.894
.13	8.861	8.827	8.794	8.761	8.729	8.697	8.665	8.633	8.601	8.570
.14	8.539	8.508	8.577	8.447	8.416	8.386	8.356	8.327	8.297	8.268
.15	8.239	8.210	8.182	8.153	8.125	8.097	8.069	8.041	8.013	7.986
.16	7.959	7.932	7.905	7.878	7.852	7.825	7.799	7.773	7.747	7.721
.17	7.696	7.670	7.645	7.620	7.595	7.570	7.545	7.520	7.496	7.471
.18	7.447	7.423	7.399	7.375	7.352	7.328	7.305	7.282	7.258	7.235
.19	7.212	7.190	7.167	7.144	7.122	7.100	7.077	7.055	7.033	7.011
.20	6.990	6.968	6.946	6.925	6.904	6.882	6.861	6.840	6.819	6.799
.21	6.778	6.757	6.737	6.716	6.696	6.676	6.655	6.635	6.615	6.596
.22	6.576	6.556	6.536	6.517	6.498	6.478	6.459	6.440	6.421	6.402
.23	6.383	6.364	6.345	6.326	6.308	6.289	6.271	6.253	6.234	6.216
.24	6.198	6.180	6.162	6.144	6.126	6.108	6.091	6.073	6.055	6.038
.25	6.021	6.003	5.986	5.969	5.952	5.935	5.918	5.901	5.884	5.867
.26	5.850	5.834	5.817	5.800	5.784	5.768	5.751	5.735	5.719	5.702
.27	5.686	5.670	5.654	5.638	5.622	5.607	5.591	5.575	5.560	5.544
.28	5.528	5.513	5.498	5.482	5.467	5.452	5.436	5.421	5.406	5.391
.29	5.376	5.361	5.346	5.331	5.317	5.302	5.287	5.272	5.258	5.243
.30	5.229	5.214	5.200	5.186	5.171	5.157	5.143	5.129	5.114	5.100
.31	5.086	5.072	5.058	5.045	5.031	5.017	5.003	4.984	4.976	4.962
.32	4.949	4.935	4.921	4.908	4.895	4.881	4.868	4.855	4.841	4.828
.33	4.815	4.802	4.789	4.776	4.763	4.750	4.737	4.724	4.711	4.698
.34	4.685	4.672	4.660	4.647	4.634	4.622	4.609	4.597	4.584	4.572
.35	4.559	4.547	4.535	4.522	4.510	4.498	4.486	4.473	4.461	4.449
.36	4.437	4.425	4.413	4.401	4.389	4.377	4.365	4.353	4.342	4.330
.37	4.318	4.306	4.295	4.283	4.271	4.260	4.248	4.237	4.225	4.214
.38	4.202	4.191	4.179	4.168	4.157	4.145	4.134	4.123	4.112	4.101
.39	4.089	4.078	4.067	4.056	4.045	4.034	4.023	4.012	4.001	3.990
.40	3.979	3.969	3.958	3.947	3.936	3.925	3.915	3.904	3.893	3.883
.41	3.872	3.862	3.851	3.840	3.830	3.820	3.809	3.799	3.788	3.778
.42	3.768	3.757	3.747	3.737	3.726	3.716	3.706	3.696	3.686	3.675
.43	3.665	3.655	3.645	3.635	3.625	3.615	3.605	3.595	3.585	3.575
.44	3.565	3.556	3.546	3.536	3.526	3.516	3.507	3.497	3.487	3.478

TABLE P5 continued

Power Ratio	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.45	3.468	3.458	3.449	3.439	3.429	3.420	3.410	3.401	3.391	3.382
.46	3.372	3.363	3.354	3.344	3.335	3.325	3.316	3.307	3.298	3.288
.47	3.279	3.270	3.261	3.251	3.242	3.233	3.224	3.215	3.206	3.197
.48	3.188	3.179	3.170	3.161	3.152	3.143	3.134	3.125	3.116	3.107
.49	3.098	3.089	3.080	3.072	3.063	3.054	3.045	9.036	3.028	3.019
.50	3.010	3.002	2.993	2.984	2.933	2.976	2.967	2.958	2.950	2.941
.51	2.924	2.916	2.907	2.899	2.890	2.882	2.874	2.865	2.857	2.848
.52	2.840	2.832	2.823	2.815	2.765	2.807	2.798	2.790	2.782	2.774
.53	2.757	2.749	2.741	2.733	2.684	2.725	2.716	2.708	2.700	2.692
.54	2.676	2.668	2.660	2.652	2.604	2.644	2.636	2.628	2.620	2.612
.55	2.596	2.588	2.581	2.573	2.565	2.557	2.549	2.541	2.534	2.526
.56	2.518	2.510	2.503	2.495	2.487	2.480	2.472	2.464	2.457	2.449
.57	2.441	2.434	2.426	2.418	2.411	2.403	2.396	2.388	2.381	2.373
.58	2.366	2.358	2.351	2.343	2.336	2.328	2.321	2.314	2.306	2.299
.59	2.291	2.284	2.277	2.269	2.262	2.255	2.248	2.240	2.233	2.226
.60	2.218	2.211	2.204	2.197	2.190	2.182	2.175	2.168	2.161	2.154
.61	2.147	2.140	2.132	2.125	2.118	2.111	2.104	2.097	2.090	2.083
.62	2.076	2.069	2.062	2.055	2.048	2.041	2.034	2.027	2.020	2.013
.63	2.007	2.000	1.993	1.986	1.979	1.972	1.965	1.959	1.952	1.945
.64	1.938	1.931	1.925	1.918	1.911	1.904	1.897	1.891	1.884	1.878
.65	1.871	1.864	1.858	1.851	1.844	1.838	1.831	1.824	1.818	1.811
.66	1.805	1.798	1.791	1.785	1.778	1.772	1.765	1.759	1.752	1.746
.67	1.739	1.733	1.726	1.720	1.713	1.707	1.701	1.694	1.688	1.681
.68	1.675	1.669	1.662	1.656	1.649	1.643	1.637	1.630	1.624	1.618
.69	1.612	1.605	1.599	1.593	1.586	1.580	1.574	1.568	1.561	1.555
.70	1.549	1.543	1.537	1.530	1.524	1.518	1.512	1.506	1.500	1.494
.71	1.487	1.481	1.475	1.469	1.463	1.457	1.451	1.445	1.439	1.433
.72	1.427	1.421	1.415	1.409	1.403	1.397	1.391	1.385	1.379	1.373
.73	1.367	1.361	1.355	1.349	1.343	1.337	1.331	1.325	1.319	1.314
.74	1.308	1.302	1.296	1.290	1.284	1.278	1.273	1.267	1.261	1.255
.75	1.249	1.244	1.238	1.232	1.226	1.221	1.215	1.209	1.203	1.198
.76	1.192	1.186	1.180	1.175	1.169	1.163	1.158	1.152	1.146	1.141
.77	1.135	1.129	1.124	1.118	1.113	1.107	1.101	1.096	1.090	1.085
.78	1.079	1.073	1.068	1.062	1.057	1.051	1.046	1.040	1.035	1.029
.79	1.024	1.018	1.013	1.007	1.002	.996	.991	.985	.980	.975
.80	.969	.964	.958	.953	.947	.942	.937	.931	.926	.921
.81	.915	.910	.904	.899	.894	.888	.883	.878	.872	.867
.82	.862	.857	.851	.846	.841	.835	.830	.825	.820	.814
.83	.809	.804	.799	.794	.788	.783	.778	.773	.768	.762
.84	.757	.752	.747	.742	.737	.731	.726	.721	.716	.711
.85	.706	.701	.696	.691	.685	.680	.675	.670	.665	.660
.86	.655	.650	.645	.640	.635	.630	.625	.620	.615	.610
.87	.605	.600	.595	.590	.585	.580	.575	.570	.565	.560
.88	.555	.550	.545	.540	.535	.531	.526	.521	.516	.511
.89	.506	.501	.496	.491	.487	.482	.477	.472	.467	.462
.90	.458	.453	.448	.443	.438	.434	.429	.424	.419	.414
.91	.410	.405	.400	.395	.391	.386	.381	.376	.372	.367
.92	.362	.357	.353	.348	.343	.339	.334	.329	.325	.320
.93	.315	.311	.306	.301	.297	.292	.287	.283	.278	.273
.94	.269	.264	.259	.255	.250	.246	.241	.237	.232	.227
.95	.223	.218	.214	.209	.205	.200	.195	.191	.186	.182
.96	.177	.173	.168	.164	.159	.155	.150	.146	.141	.137
.97	.132	.128	.123	.119	.114	.110	.106	.101	.097	.092
.98	.088	.083	.079	.074	.070	.066	.061	.057	.052	.048
.99	.044	.039	.035	.031	.026	.022	.017	.013	.009	.004

TABLE P6 GIVEN: −dB (0 to −10); FIND: POWER RATIO (1.0 to 0.1)

For −dB below −10:

1. Add dBs as required to give a number between 0 and −10.
2. Look up power ratio corresponding to this number of dBs in Table P6.
3. Multiply the power ratio found by the number corresponding to dBs added in step 1.

For dBs Added	Multiply By	For dBs Added	Multiply By
10	0.1	50	10^{-5}
20	0.01	60	10^{-6}
30	0.001	70	10^{-7}
40	0.0001	80	10^{-8}

Example: Given −37.21 dB. Add 30 dB to get −7.21 dB. From Table P6, ratio corresponding to −7.21 dB is 0.1901. Corresponding to the 30 dBs added, multiply 0.1901 x 0.001 to get power ratio of 0.0001901 or **1.901×10^{-4}**.

dB	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	1.0000	.9977	.9954	.9931	.9908	.9886	.9863	.9840	.9817	.9795
−0.1	.9772	.9750	.9727	.9705	.9683	.9661	.9638	.9616	.9594	.9572
−0.2	.9550	.9528	.9506	.9484	.9462	.9441	.9419	.9397	.9376	.9354
−0.3	.9333	.9311	.9290	.9268	.9247	.9226	.9204	.9183	.9162	.9141
−0.4	.9120	.9099	.9078	.9057	.9036	.9016	.8995	.8974	.8954	.8933
−0.5	.8913	.8892	.8872	.8851	.8831	.8810	.8790	.8770	.8750	.8730
−0.6	.8710	.8690	.8670	.8650	.8630	.8610	.8590	.8570	.8551	.8531
−0.7	.8511	.8492	.8472	.8453	.8433	.8414	.8395	.8375	.8356	.8337
−0.8	.8318	.8299	.8279	.8260	.8241	.8222	.8204	.8185	.8166	.8147
−0.9	.8128	.8110	.8091	.8072	.8054	.8035	.8017	.7998	.7980	.7962
−1.0	.7943	.7925	.7907	.7889	.7870	.7852	.7834	.7816	.7798	.7780
−1.1	.7762	.7745	.7727	.7709	.7691	.7674	.7656	.7638	.7621	.7603
−1.2	.7586	.7568	.7551	.7534	.7516	.7499	.7482	.7464	.7447	.7430
−1.3	.7413	.7396	.7379	.7362	.7345	.7328	.7311	.7295	.7278	.7261
−1.4	.7244	.7228	.7211	.7194	.7178	.7161	.7145	.7129	.7112	.7096
−1.5	.7079	.7063	.7047	.7031	.7015	.6998	.6982	.6966	.6950	.6934
−1.6	.6918	.6902	.6887	.6871	.6855	.6839	.6823	.6808	.6792	.6776
−1.7	.6761	.6745	.6730	.6714	.6699	.6683	.6668	.6653	.6637	.6622
−1.8	.6607	.6592	.6577	.6561	.6546	.6531	.6516	.6501	.6486	.6471
−1.9	.6457	.6442	.6427	.6412	.6397	.6383	.6368	.6353	.6339	.6324
−2.0	.6310	.6295	.6281	.6266	.6252	.6237	.6223	.6209	.6194	.6180
−2.1	.6166	.6152	.6138	.6124	.6109	.6095	.6081	.6067	.6053	.6039
−2.2	.6026	.6012	.5998	.5984	.5970	.5957	.5943	.5929	.5916	.5902
−2.3	.5888	.5875	.5861	.5848	.5834	.5821	.5808	.5794	.5781	.5768
−2.4	.5754	.5741	.5728	.5715	.5702	.5689	.5675	.5662	.5649	.5636
−2.5	.5623	.5610	.5598	.5585	.5572	.5559	.5546	.5534	.5521	.5508
−2.6	.5495	.5483	.5470	.5458	.5445	.5433	.5420	.5408	.5395	.5383
−2.7	.5370	.5358	.5346	.5333	.5321	.5309	.5297	.5284	.5272	.5260
−2.8	.5248	.5236	.5224	.5212	.5200	.5188	.5176	.5164	.5152	.5140
−2.9	.5129	.5117	.5105	.5093	.5082	.5070	.5058	.5047	.5035	.5023
−3.0	.5012	.5000	.4989	.4977	.4966	.4955	.4943	.4932	.4920	.4909
−3.1	.4898	.4887	.4875	.4864	.4853	.4842	.4831	.4819	.4808	.4797
−3.2	.4786	.4775	.4764	.4753	.4742	.4732	.4721	.4710	.4699	.4688
−3.3	.4677	.4667	.4656	.4645	.4634	.4624	.4613	.4603	.4592	.4581
−3.4	.4571	.4560	.4550	.4539	.4529	.4519	.4508	.4498	.4487	.4477
−3.5	.4467	.4457	.4446	.4436	.4426	.4416	.4406	.4395	.4385	.4375
−3.6	.4365	.4355	.4345	.4335	.4325	.4315	.4305	.4295	.4285	.4276
−3.7	.4266	.4256	.4246	.4236	.4227	.4217	.4207	.4198	.4188	.4178
−3.8	.4169	.4159	.4150	.4140	.4130	.4121	.4111	.4102	.4093	.4083
−3.9	.4074	.4064	.4055	.4046	.4036	.4027	.4018	.4009	.3999	.3990
−4.0	.3981	.3972	.3963	.3954	.3945	.3936	.3926	.3917	.3908	.3899
−4.1	.3890	.3882	.3873	.3864	.3855	.3846	.3837	.3828	.3819	.3811
−4.2	.3802	.3793	.3784	.3776	.3767	.3758	.3750	.3741	.3733	.3724
−4.3	.3715	.3707	.3698	.3690	.3681	.3673	.3664	.3656	.3648	.3639
−4.4	.3631	.3622	.3614	.3606	.3597	.3589	.3581	.3573	.3565	.3556

TABLE P6 continued

dB	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
−4.5	.3548	.3540	.3532	.3524	.3516	.3508	.3499	.3491	.3483	.3475
−4.6	.3467	.3459	.3451	.3443	.3436	.3428	.3420	.3412	.3404	.3396
−4.7	.3388	.3381	.3373	.3365	.3357	.3350	.3342	.3334	.3327	.3319
−4.8	.3311	.3304	.3296	.3289	.3281	.3273	.3266	.3258	.3251	.3243
−4.9	.3236	.3228	.3221	.3214	.3206	.3199	.3192	.3184	.3177	.3170
−5.0	.3162	.3155	.3148	.3141	.3133	.3126	.3119	.3112	.3105	.3097
−5.1	.3090	.3083	.3076	.3069	.3062	.3055	.3048	.3041	.3034	.3027
−5.2	.3020	.3013	.3006	.2999	.2992	.2985	.2979	.2972	.2965	.2958
−5.3	.2951	.2944	.2938	.2931	.2924	.2917	.2911	.2904	.2897	.2891
−5.4	.2884	.2877	.2871	.2864	.2858	.2851	.2844	.2838	.2831	.2825
−5.5	.2818	.2812	.2805	.2799	.2793	.2786	.2780	.2773	.2767	.2761
−5.6	.2754	.2748	.2742	.2735	.2729	.2723	.2716	.2710	.2704	.2698
−5.7	.2692	.2685	.2679	.2673	.2667	.2661	.2655	.2649	.2642	.2636
−5.8	.2630	.2624	.2618	.2612	.2606	.2600	.2594	.2588	.2582	.2576
−5.9	.2570	.2564	.2559	.2553	.2547	.2541	.2535	.2529	.2523	.2518
−6.0	.2512	.2506	.2500	.2495	.2489	.2483	.2477	.2472	.2466	.2460
−6.1	.2455	.2449	.2443	.2438	.2432	.2427	.2421	.2415	.2410	.2404
−6.2	.2399	.2393	.2388	.2382	.2377	.2371	.2366	.2360	.2355	.2350
−6.3	.2344	.2339	.2333	.2328	.2323	.2317	.2312	.2307	.2301	.2296
−6.4	.2291	.2286	.2280	.2275	.2270	.2265	.2259	.2254	.2249	.2244
−6.5	.2239	.2234	.2228	.2223	.2218	.2213	.2208	.2203	.2198	.2193
−6.6	.2188	.2183	.2178	.2173	.2168	.2163	.2158	.2153	.2148	.2143
−6.7	.2138	.2133	.2128	.2123	.2118	.2113	.2109	.2104	.2099	.2094
−6.8	.2089	.2084	.2080	.2075	.2070	.2065	.2061	.2056	.2051	.2046
−6.9	.2042	.2037	.2032	.2028	.2023	.2018	.2014	.2009	.2004	.2000
−7.0	.1995	.1991	.1986	.1982	.1977	.1972	.1968	.1963	.1959	.1954
−7.1	.1950	.1945	.1941	.1936	.1932	.1928	.1923	.1919	.1914	.1910
−7.2	.1905	.1901	.1897	.1892	.1888	.1884	.1879	.1875	.1871	.1866
−7.3	.1862	.1858	.1854	.1849	.1845	.1841	.1837	.1832	.1828	.1824
−7.4	.1820	.1816	.1811	.1807	.1803	.1799	.1795	.1791	.1786	.1782
−7.5	.1778	.1774	.1770	.1766	.1762	.1758	.1754	.1750	.1746	.1742
−7.6	.1738	.1734	.1730	.1726	.1722	.1718	.1714	.1710	.1706	.1702
−7.7	.1698	.1694	.1690	.1687	.1683	.1679	.1675	.1671	.1667	.1663
−7.8	.1660	.1656	.1652	.1648	.1644	.1641	.1637	.1633	.1629	.1626
−7.9	.1622	.1618	.1614	.1611	.1607	.1603	.1600	.1596	.1592	.1589
−8.0	.1585	.1581	.1578	.1574	.1570	.1567	.1563	.1560	.1556	.1552
−8.1	.1549	.1545	.1542	.1538	.1535	.1531	.1528	.1524	.1521	.1517
−8.2	.1514	.1510	.1507	.1503	.1500	.1496	.1493	.1489	.1486	.1483
−8.3	.1479	.1476	.1472	.1469	.1466	.1462	.1459	.1455	.1452	.1449
−8.4	.1445	.1442	.1439	.1435	.1432	.1429	.1426	.1422	.1419	.1416
−8.5	.1413	.1409	.1406	.1403	.1400	.1396	.1393	.1390	.1387	.1384
−8.6	.1380	.1377	.1374	.1371	.1368	.1365	.1361	.1358	.1355	.1352
−8.7	.1349	.1346	.1343	.1340	.1337	.1334	.1330	.1327	.1324	.1321
−8.8	.1318	.1315	.1312	.1309	.1306	.1303	.1300	.1297	.1294	.1291
−8.9	.1288	.1285	.1282	.1279	.1276	.1274	.1271	.1268	.1265	.1262
−9.0	.1259	.1256	.1253	.1250	.1247	.1245	.1242	.1239	.1236	.1233
−9.1	.1230	.1227	.1225	.1222	.1219	.1216	.1213	.1211	.1208	.1205
−9.2	.1202	.1199	.1197	.1194	.1191	.1189	.1186	.1183	.1180	.1178
−9.3	.1175	.1172	.1169	.1167	.1164	.1161	.1159	.1156	.1153	.1151
−9.4	.1148	.1146	.1143	.1140	.1138	.1135	.1132	.1130	.1127	.1125
−9.5	.1122	.1119	.1117	.1114	.1112	.1109	.1107	.1104	.1102	.1099
−9.6	.1096	.1094	.1091	.1089	.1086	.1084	.1081	.1079	.1076	.1074
−9.7	.1072	.1069	.1067	.1064	.1062	.1059	.1057	.1054	.1052	.1050
−9.8	.1047	.1045	.1042	.1040	.1038	.1035	.1033	.1030	.1028	.1026
−9.9	.1023	.1021	.1019	.1016	.1014	.1012	.1009	.1007	.1005	.1002
−10.0	.1000	.0998	.0995	.0993	.0991	.0989	.0987	.0984	.0982	.0980

TABLE P7 GIVEN: POWER RATIO (1.0 to 10.0); FIND: +dB (0 to +10)

For power ratios greater than 10:

1. Divide by the multiple of 10 required to give a number between 1.0 and 10.0.
2. Look up + dB corresponding to this number in Table P7.
3. Add to the result +dBs corresponding to the multiple of 10 used in step 1.

Multiple of 10	Add dBs	Multiple of 10	Add dBs
10	10	10^5	50
10^2	20	10^6	60
10^3	30	10^7	70
10^4	40	10^8	80

Example: Given power ratio = 397,000 (3.97×10^5). Divide by 10^5 to get 3.97. From Table P7, dBs corresponding to 3.97 is 5.988. Adding 50 dB (corresponding to the 10^5 multiplier used) we get 5.988 + 50 = **55.988 dB.**

Power Ratio	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
1.0	.000	.043	.086	.128	.170	.212	.253	.294	.334	.374
1.1	.414	.453	.492	.531	.569	.607	.645	.682	.719	.755
1.2	.792	.828	.864	.899	.934	.969	1.004	1.038	1.072	1.106
1.3	1.139	1.173	1.206	1.239	1.271	1.303	1.335	1.367	1.399	1.430
1.4	1.461	1.492	1.523	1.553	1.584	1.614	1.644	1.673	1.703	1.732
1.5	1.761	1.790	1.818	1.847	1.875	1.903	1.931	1.959	1.987	2.014
1.6	2.041	2.068	2.095	2.122	2.148	2.175	2.201	2.227	2.253	2.279
1.7	2.304	2.330	2.355	2.380	2.405	2.430	2.455	2.480	2.504	2.529
1.8	2.553	2.577	2.601	2.625	2.648	2.672	2.695	2.718	2.742	2.765
1.9	2.788	2.810	2.833	2.856	2.878	2.900	2.923	2.945	2.967	2.989
2.0	3.010	3.032	3.054	3.075	3.096	3.118	3.139	3.160	3.181	3.201
2.1	3.222	3.243	3.263	3.284	3.304	3.324	3.345	3.365	3.385	3.404
2.2	3.424	3.444	3.464	3.483	3.502	3.522	3.541	3.560	3.579	3.598
2.3	3.617	3.636	3.655	3.674	3.692	3.711	3.729	3.747	3.766	3.784
2.4	3.802	3.820	3.838	3.856	3.874	3.892	3.909	3.927	3.945	3.962
2.5	3.979	3.997	4.014	4.031	4.048	4.065	4.082	4.099	4.116	4.133
2.6	4.150	4.166	4.183	4.200	4.216	4.232	4.249	4.265	4.281	4.298
2.7	4.314	4.330	4.346	4.362	4.378	4.393	4.409	4.425	4.440	4.456
2.8	4.472	4.487	4.502	4.518	4.533	4.548	4.564	4.579	4.594	4.609
2.9	4.624	4.639	4.654	4.669	4.683	4.698	4.713	4.728	4.742	4.757
3.0	4.771	4.786	4.800	4.814	4.829	4.843	4.857	4.871	4.886	4.900
3.1	4.914	4.928	4.942	4.955	4.969	4.983	4.997	5.011	5.024	5.038
3.2	5.051	5.065	5.079	5.092	5.105	5.119	5.132	5.145	5.159	5.172
3.3	5.185	5.198	5.211	5.224	5.237	5.250	5.263	5.276	5.289	5.302
3.4	5.315	5.328	5.340	5.353	5.366	5.378	5.391	5.403	5.416	5.428
3.5	5.441	5.453	5.465	5.478	5.490	5.502	5.514	5.527	5.539	5.551
3.6	5.563	5.575	5.587	5.599	5.611	5.623	5.635	5.647	5.658	5.670
3.7	5.682	5.694	5.705	5.717	5.729	5.740	5.752	5.763	5.775	5.786
3.8	5.798	5.809	5.821	5.832	5.843	5.855	5.866	5.877	5.888	5.899
3.9	5.911	5.922	5.933	5.944	5.955	5.966	5.977	5.988	5.999	6.010
4.0	6.021	6.031	6.042	6.053	6.064	6.075	6.085	6.096	6.107	6.117
4.1	6.128	6.138	6.149	6.160	6.170	6.180	6.191	6.201	6.212	6.222
4.2	6.232	6.243	6.253	6.263	6.274	6.284	6.294	6.304	6.314	6.325
4.3	6.335	6.345	6.355	6.365	6.375	6.385	6.395	6.405	6.415	6.425
4.4	6.435	6.444	6.454	6.464	6.474	6.484	6.493	6.503	6.513	6.522
4.5	6.532	6.542	6.551	6.561	6.571	6.580	6.590	6.599	6.609	6.618
4.6	6.628	6.637	6.646	6.656	6.665	6.675	6.684	6.693	6.702	6.712
4.7	6.721	6.730	6.739	6.749	6.758	6.767	6.776	6.785	6.794	6.803
4.8	6.812	6.821	6.830	6.839	6.848	6.857	6.866	6.875	6.884	6.893
4.9	6.902	6.911	6.920	6.928	6.937	6.946	6.955	6.964	6.972	6.981

TABLE P7 continued

Power Ratio	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
5.0	6.990	6.998	7.007	7.016	7.024	7.033	7.042	7.050	7.059	7.067
5.1	7.076	7.084	7.093	7.101	7.110	7.118	7.126	7.135	7.143	7.152
5.2	7.160	7.168	7.177	7.185	7.193	7.202	7.210	7.218	7.226	7.235
5.3	7.243	7.251	7.259	7.267	7.275	7.284	7.292	7.300	7.308	7.316
5.4	7.324	7.332	7.340	7.348	7.356	7.364	7.372	7.380	7.388	7.396
5.5	7.404	7.412	7.419	7.427	7.435	7.443	7.451	7.459	7.466	7.474
5.6	7.482	7.490	7.497	7.505	7.513	7.520	7.528	7.536	7.543	7.551
5.7	7.559	7.566	7.574	7.582	7.589	7.597	7.604	7.612	7.619	7.627
5.8	7.634	7.642	7.649	7.657	7.664	7.672	7.679	7.686	7.694	7.701
5.9	7.709	7.716	7.723	7.731	7.738	7.745	7.752	7.760	7.767	7.774
6.0	7.782	7.789	7.796	7.803	7.810	7.818	7.825	7.832	7.839	7.846
6.1	7.853	7.860	7.868	7.875	7.882	7.889	7.896	7.903	7.910	7.917
6.2	7.924	7.931	7.938	7.945	7.952	7.959	7.966	7.973	7.980	7.987
6.3	7.993	8.000	8.007	8.014	8.021	8.028	8.035	8.041	8.048	8.055
6.4	8.062	8.069	8.075	8.082	8.089	8.096	8.102	8.109	8.116	8.122
6.5	8.129	8.136	8.142	8.149	8.156	8.162	8.169	8.176	8.182	8.189
6.6	8.195	8.202	8.209	8.215	8.222	8.228	8.235	8.241	8.248	8.254
6.7	8.261	8.267	8.274	8.280	8.287	8.293	8.299	8.306	8.312	8.319
6.8	8.325	8.331	8.338	8.344	8.351	8.357	8.363	8.370	8.376	8.382
6.9	8.388	8.395	8.401	8.407	8.414	8.420	8.426	8.432	8.439	8.445
7.0	8.451	8.457	8.463	8.470	8.476	8.482	8.488	8.494	8.500	8.506
7.1	8.513	8.519	8.525	8.531	8.537	8.543	8.549	8.555	8.561	8.567
7.2	8.573	8.579	8.585	8.591	8.597	8.603	8.609	8.615	8.621	8.627
7.3	8.633	8.639	8.645	8.651	8.657	8.663	8.669	8.675	8.681	8.686
7.4	8.692	8.698	8.704	8.710	8.716	8.722	8.727	8.733	8.739	8.745
7.5	8.751	8.756	8.762	8.768	8.774	8.779	8.785	8.791	8.797	8.802
7.6	8.808	8.814	8.820	8.825	8.831	8.837	8.842	8.848	8.854	8.859
7.7	8.865	8.871	8.876	8.882	8.887	8.893	8.899	8.904	8.910	8.915
7.8	8.921	8.927	8.932	8.938	8.943	8.949	8.954	8.960	8.965	8.971
7.9	8.976	8.982	8.987	8.993	8.998	9.004	9.009	9.015	9.020	9.025
8.0	9.031	9.036	9.042	9.047	9.053	9.058	9.063	9.069	9.074	9.079
8.1	9.085	9.090	9.096	9.101	9.106	9.112	9.117	9.122	9.128	9.133
8.2	9.138	9.143	9.149	9.154	9.159	9.165	9.170	9.175	9.180	9.186
8.3	9.191	9.196	9.201	9.206	9.212	9.217	9.222	9.227	9.232	9.238
8.4	9.243	9.248	9.253	9.258	9.263	9.269	9.274	9.279	9.284	9.289
8.5	9.294	9.299	9.304	9.309	9.315	9.320	9.325	9.330	9.335	9.340
8.6	9.345	9.350	9.355	9.360	9.365	9.370	9.375	9.380	9.385	9.390
8.7	9.395	9.400	9.405	9.410	9.415	9.420	9.425	9.430	9.435	9.440
8.8	9.445	9.450	9.455	9.460	9.465	9.469	9.474	9.479	9.484	9.489
8.9	9.494	9.499	9.504	9.509	9.513	9.518	9.523	9.528	9.533	9.538
9.0	9.542	9.547	9.552	9.557	9.562	9.566	9.571	9.576	9.581	9.586
9.1	9.590	9.595	9.600	9.605	9.609	9.614	9.619	9.624	9.628	9.633
9.2	9.638	9.643	9.647	9.652	9.657	9.661	9.666	9.671	9.675	9.680
9.3	9.685	9.689	9.694	9.699	9.703	9.708	9.713	9.717	9.722	9.727
9.4	9.731	9.736	9.741	9.745	9.750	9.754	9.759	9.763	9.768	9.773
9.5	9.777	9.782	9.786	9.791	9.795	9.800	9.805	9.809	9.814	9.818
9.6	9.823	9.827	9.832	9.836	9.841	9.845	9.850	9.854	9.859	9.863
9.7	9.868	9.872	9.877	9.881	9.886	9.890	9.894	9.899	9.903	9.908
9.8	9.912	9.917	9.921	9.926	9.930	9.934	9.939	9.943	9.948	9.952
9.9	9.956	9.961	9.965	9.969	9.974	9.978	9.983	9.987	9.991	9.996
10.0	10.000	10.004	10.009	10.013	10.017	10.022	10.026	10.030	10.035	10.039

TABLE P8 GIVEN +dB (0 to +10); FIND: POWER RATIO (1.0 to 10.0)

For +dBs greater than +10:

1. Subtract dBs as required to give a number between 0 and 10.
2. Look up power ratio corresponding to this number of dBs in Table P8.
3. Multiply the power ratio found by the number corresponding to the dBs subtracted in step 1.

For dBs Subtracted	Multiply By	For dBs Subtracted	Multiply By
10	10	50	10^5
20	10^2	60	10^6
30	10^3	70	10^7
40	10^4	80	10^8

Example: Given 76.21 dB. Subtract 70 dB to get 6.21 dB. From Table P8, power ratio for 6.21 dB is 4.178. Corresponding to the 70 dBs subtracted, multiply 4.178×10^7 to get power ratio of **41,780,000.**

dB	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.00	1.000	1.002	1.005	1.007	1.009	1.012	1.014	1.016	1.019	1.021
0.10	1.023	1.026	1.028	1.030	1.033	1.035	1.038	1.040	1.042	1.045
0.20	1.047	1.050	1.052	1.054	1.057	1.059	1.062	1.064	1.067	1.069
0.30	1.072	1.074	1.076	1.079	1.081	1.084	1.086	1.089	1.091	1.094
0.40	1.096	1.099	1.102	1.104	1.107	1.109	1.112	1.114	1.117	1.119
0.50	1.122	1.125	1.127	1.130	1.132	1.135	1.138	1.140	1.143	1.146
0.60	1.148	1.151	1.153	1.156	1.159	1.161	1.164	1.167	1.169	1.172
0.70	1.175	1.178	1.180	1.183	1.186	1.189	1.191	1.194	1.197	1.199
0.80	1.202	1.205	1.208	1.211	1.213	1.216	1.219	1.222	1.225	1.227
0.90	1.230	1.233	1.236	1.239	1.242	1.245	1.247	1.250	1.253	1.256
1.00	1.259	1.262	1.265	1.268	1.271	1.274	1.276	1.279	1.282	1.285
1.10	1.288	1.291	1.294	1.297	1.300	1.303	1.306	1.309	1.312	1.315
1.20	1.318	1.321	1.324	1.327	1.330	1.334	1.337	1.340	1.343	1.346
1.30	1.349	1.352	1.355	1.358	1.361	1.365	1.368	1.371	1.374	1.377
1.40	1.380	1.384	1.387	1.390	1.393	1.396	1.400	1.403	1.406	1.409
1.50	1.413	1.416	1.419	1.422	1.426	1.429	1.432	1.435	1.439	1.442
1.60	1.445	1.449	1.452	1.455	1.459	1.462	1.466	1.469	1.472	1.476
1.70	1.479	1.483	1.486	1.489	1.493	1.496	1.500	1.503	1.507	1.510
1.80	1.514	1.517	1.521	1.524	1.528	1.531	1.535	1.538	1.542	1.545
1.90	1.549	1.552	1.556	1.560	1.563	1.567	1.570	1.574	1.578	1.581
2.00	1.585	1.589	1.592	1.596	1.600	1.603	1.607	1.611	1.614	1.618
2.10	1.622	1.626	1.629	1.633	1.637	1.641	1.644	1.648	1.652	1.656
2.20	1.660	1.663	1.667	1.671	1.675	1.679	1.683	1.687	1.690	1.694
2.30	1.698	1.702	1.706	1.710	1.714	1.718	1.722	1.726	1.730	1.734
2.40	1.738	1.742	1.746	1.750	1.754	1.758	1.762	1.766	1.770	1.774
2.50	1.778	1.782	1.786	1.791	1.795	1.799	1.803	1.807	1.811	1.816
2.60	1.820	1.824	1.828	1.832	1.837	1.841	1.845	1.849	1.854	1.858
2.70	1.862	1.866	1.871	1.875	1.879	1.884	1.888	1.892	1.897	1.901
2.80	1.905	1.910	1.914	1.919	1.923	1.928	1.932	1.936	1.941	1.945
2.90	1.950	1.954	1.959	1.963	1.968	1.972	1.977	1.982	1.986	1.991
3.00	1.995	2.000	2.004	2.009	2.014	2.018	2.023	2.028	2.032	2.037
3.10	2.042	2.046	2.051	2.056	2.061	2.065	2.070	2.075	2.080	2.084
3.20	2.089	2.094	2.099	2.104	2.109	2.113	2.118	2.123	2.128	2.133
3.30	2.138	2.143	2.148	2.153	2.158	2.163	2.168	2.173	2.178	2.183
3.40	2.188	2.193	2.198	2.203	2.208	2.213	2.218	2.223	2.228	2.234
3.50	2.239	2.244	2.249	2.254	2.259	2.265	2.270	2.275	2.280	2.286
3.60	2.291	2.296	2.301	2.307	2.312	2.317	2.323	2.328	2.333	2.339
3.70	2.344	2.350	2.355	2.360	2.366	2.371	2.377	2.382	2.388	2.393
3.80	2.399	2.404	2.410	2.415	2.421	2.427	2.432	2.438	2.443	2.449
3.90	2.455	2.460	2.466	2.472	2.477	2.483	2.489	2.495	2.500	2.506
4.00	2.512	2.518	2.523	2.529	2.535	2.541	2.547	2.553	2.559	2.564
4.10	2.570	2.576	2.582	2.588	2.594	2.600	2.606	2.612	2.618	2.624
4.20	2.630	2.636	2.642	2.649	2.655	2.661	2.667	2.673	2.679	2.685
4.30	2.692	2.698	2.704	2.710	2.716	2.723	2.729	2.735	2.742	2.748
4.40	2.754	2.761	2.767	2.773	2.780	2.786	2.793	2.799	2.805	2.812

TABLE P8 continued

dB	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
4.50	2.818	2.825	2.831	2.838	2.844	2.851	2.858	2.864	2.871	2.877
4.60	2.884	2.891	2.897	2.904	2.911	2.917	2.924	2.931	2.938	2.944
4.70	2.951	2.958	2.965	2.972	2.979	2.985	2.992	2.999	3.006	3.013
4.80	3.020	3.027	3.034	3.041	3.048	3.055	3.062	3.069	3.076	3.083
4.90	3.090	3.097	3.105	3.112	3.119	3.126	3.133	3.141	3.148	3.155
5.00	3.162	3.170	3.177	3.184	3.192	3.199	3.206	3.214	3.221	3.228
5.10	3.236	3.243	3.251	3.258	3.266	3.273	3.281	3.289	3.296	3.304
5.20	3.311	3.319	3.327	3.334	3.342	3.350	3.357	3.365	3.373	3.381
5.30	3.388	3.396	3.404	3.412	3.420	3.428	3.436	3.443	3.451	3.459
5.40	3.467	3.475	3.483	3.491	3.499	3.508	3.516	3.524	3.532	3.540
5.50	3.548	3.556	3.565	3.573	3.581	3.589	3.597	3.606	3.614	3.622
5.60	3.631	3.639	3.648	3.656	3.664	3.673	3.681	3.690	3.698	3.707
5.70	3.715	3.724	3.733	3.741	3.750	3.758	3.767	3.776	3.784	3.793
5.80	3.802	3.811	3.819	3.828	3.837	3.846	3.855	3.864	3.873	3.882
5.90	3.890	3.899	3.908	3.917	3.926	3.936	3.945	3.954	3.963	3.972
6.00	3.981	3.990	3.999	4.009	4.018	4.027	4.036	4.046	4.055	0.064
6.10	4.074	4.083	4.093	4.102	4.111	4.121	4.130	4.140	4.150	4.159
6.20	4.169	4.178	4.188	4.198	4.207	4.217	4.227	4.236	4.246	4.256
6.30	4.266	4.276	4.285	4.295	4.305	4.315	4.325	4.335	4.345	4.355
6.40	4.365	4.375	4.385	4.395	4.406	4.416	4.426	4.436	4.446	4.457
6.50	4.467	4.477	4.487	4.498	4.508	4.519	4.529	4.539	4.550	4.560
6.60	4.571	4.581	4.592	4.603	4.613	4.624	4.634	4.645	4.656	4.667
6.70	4.677	4.688	4.699	4.710	4.721	4.732	4.742	4.753	4.764	4.775
6.80	4.786	4.797	4.808	4.819	4.831	4.842	4.853	4.864	4.875	4.887
6.90	4.898	4.909	4.920	4.932	4.943	4.955	4.966	4.977	4.989	5.000
7.00	5.012	5.023	5.035	5.047	5.058	5.070	5.082	5.093	5.105	5.117
7.10	5.129	5.140	5.152	5.164	5.176	5.188	5.200	5.212	5.224	5.236
7.20	5.248	5.260	5.272	5.284	5.297	5.309	5.321	5.333	5.346	5.358
7.30	5.370	5.383	5.395	5.408	5.420	5.433	5.445	5.458	5.470	5.483
7.40	5.495	5.508	5.521	5.534	5.546	5.559	5.572	5.585	5.598	5.610
7.50	5.623	5.636	5.649	5.662	5.675	5.689	5.702	5.715	5.728	5.741
7.60	5.754	5.768	5.781	5.794	5.808	5.821	5.834	5.848	5.861	5.875
7.70	5.888	5.902	5.916	5.929	5.943	5.957	5.970	5.984	5.998	6.012
7.80	6.026	6.039	6.053	6.067	6.081	6.095	6.109	6.124	6.138	6.152
7.90	6.166	6.180	6.194	6.209	6.223	6.237	6.252	6.266	6.281	6.295
8.00	6.310	6.324	6.339	6.353	6.368	6.383	6.397	6.412	6.427	6.442
8.10	6.457	6.471	6.486	6.501	6.516	6.531	6.546	6.561	6.577	6.592
8.20	6.607	6.622	6.637	6.653	6.668	6.683	6.699	6.714	6.730	6.745
8.30	6.761	6.776	6.792	6.808	6.823	6.839	6.855	6.871	6.887	6.902
8.40	6.918	6.934	6.950	6.966	6.982	6.998	7.015	7.031	7.047	7.063
8.50	7.079	7.096	7.112	7.129	7.145	7.161	7.178	1.194	7.211	7.228
8.60	7.244	7.261	7.278	7.295	7.311	7.328	7.345	7.362	7.379	7.396
8.70	7.413	7.430	7.447	7.464	7.482	7.499	7.516	7.534	7.551	7.568
8.80	7.586	7.603	7.621	7.638	7.656	7.674	7.691	7.709	7.727	7.745
8.90	7.762	7.780	7.798	7.816	7.834	7.852	7.870	7.889	7.907	7.925
9.00	7.943	7.962	7.980	7.998	8.017	8.035	8.054	8.072	8.091	8.110
9.10	8.128	8.147	8.166	8.185	8.204	8.222	8.241	8.260	8.279	8.299
9.20	8.318	8.337	8.356	8.375	8.395	8.414	8.433	8.453	8.472	8.492
9.30	8.511	8.531	8.551	8.570	8.590	8.610	8.630	8.650	8.670	8.690
9.40	8.710	8.730	8.750	8.770	8.790	8.810	8.831	8.851	8.872	8.892
9.50	8.913	8.933	8.954	8.974	8.995	9.016	9.036	9.057	9.078	9.099
9.60	9.120	9.141	9.162	9.183	9.204	9.226	9.247	9.268	9.290	9.311
9.70	9.333	9.354	9.376	9.397	9.419	9.441	9.462	9.484	9.506	9.528
9.80	9.550	9.572	9.594	9.616	9.638	9.661	9.683	9.705	9.727	9.750
9.90	9.772	9.795	9.817	9.840	9.863	9.886	9.908	9.931	9.954	9.977
10.00	10.000	10.023	10.046	10.070	10.093	10.115	10.140	10.163	10.186	10.210

TABLE P9
POWER ADDITION

TWO SIGNAL OR NOISE LEVELS COMBINED ON A **POWER** BASIS.
GIVEN: dB DIFFERENCE BETWEEN THE TWO LEVELS;
FIND: dBs TO ADD TO THE HIGHER LEVEL TO GET TOTAL LEVEL IN dBs.

dB Difference	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.0	3.01	2.96	2.91	2.86	2.82	2.77	2.72	2.67	2.63	2.58
1.0	2.54	2.50	2.45	2.41	2.37	2.33	2.28	2.24	2.20	2.16
2.0	2.13	2.09	2.05	2.01	1.97	1.94	1.90	1.87	1.83	1.80
3.0	1.76	1.73	1.70	1.67	1.64	1.60	1.57	1.54	1.51	1.48
4.0	1.46	1.43	1.40	1.37	1.35	1.32	1.29	1.27	1.24	1.22
5.0	1.19	1.17	1.15	1.12	1.10	1.08	1.06	1.04	1.01	0.99
6.0	0.97	0.95	0.93	0.91	0.90	0.88	0.86	0.84	0.82	0.81
7.0	0.79	0.77	0.76	0.74	0.72	0.71	0.70	0.68	0.67	0.65
8.0	0.64	0.62	0.61	0.60	0.59	0.57	0.56	0.55	0.54	0.53
9.0	0.51	0.50	0.49	0.48	0.47	0.46	0.45	0.44	0.43	0.42
10.0	0.41	0.40	0.39	0.39	0.38	0.37	0.36	0.35	0.35	0.34
11.0	0.33	0.32	0.31	0.31	0.30	0.30	0.29	0.28	0.28	0.27
12.0	0.26	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.22	0.22
13.0	0.21	0.21	0.20	0.20	0.19	0.19	0.19	0.18	0.18	0.17
14.0	0.17	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.14	0.14
15.0	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.11	0.11
16.0	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09
17.0	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07
18.0	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06
19.0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04
20.0	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03

TABLE P10
POWER DIVISION

A SIGNAL IS DIVIDED SO THAT THE SUM OF THE TWO OUTPUT **POWERS** EQUALS THE INPUT POWER.
GIVEN: dB DIFFERENCE BETWEEN INPUT LEVEL AND LOWER OUTPUT LEVEL;
FIND: dB DIFFERENCE BETWEEN INPUT LEVEL AND HIGHER OUTPUT LEVEL.

dB Difference	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
3.0	3.02	2.92	2.83	2.74	2.65	2.57	2.49	2.42	2.34	2.27
4.0	2.20	2.14	2.08	2.02	1.96	1.90	1.85	1.80	1.75	1.70
5.0	1.65	1.61	1.56	1.52	1.48	1.44	1.40	1.36	1.33	1.29
6.0	1.26	1.22	1.19	1.16	1.13	1.10	1.07	1.04	1.02	0.99
7.0	0.97	0.94	0.92	0.89	0.87	0.85	0.83	0.81	0.79	0.77
8.0	0.75	0.73	0.71	0.70	0.68	0.66	0.65	0.63	0.61	0.60
9.0	0.58	0.57	0.56	0.54	0.53	0.52	0.50	0.49	0.48	0.47
10.0	0.46	0.45	0.44	0.43	0.42	0.41	0.40	0.39	0.38	0.37
11.0	0.36	0.35	0.34	0.33	0.33	0.32	0.31	0.30	0.30	0.29
12.0	0.28	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.23	0.23
13.0	0.22	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.18	0.18
14.0	0.18	0.17	0.17	0.16	0.16	0.16	0.15	0.15	0.15	0.14
15.0	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.11
16.0	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.09	0.09	0.09
17.0	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07
18.0	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06
19.0	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04
20.0	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

VOLTAGE vs dB CHARTS AND TABLES

Applications of the Voltage vs. dB Charts and Tables

1. **Voltage or Current Gain or Loss:** The direct application of these tables is to cases where the dBs are related to gain or loss of voltage or current.

Example: The current gain at 100 MHz of a certain transistor is rated as 15 times. What is this in dB? From Chart V2 and Table V6 a current ratio of 15 corresponds to **23.52 dB.**

2. **Percent Voltage:** Chart V1 has scales allowing direct conversion of percent voltage to dBs. The tables relating voltage (or current) ratio to dBs can be used for percent by making use of the relation:

a smaller voltage (or current), expressed as percent of a larger = 100 times the voltage ratio $\left(\frac{\textit{smaller voltage}}{\textit{larger voltage}}\right)$

Example: When the ratio of two voltages is 0.275, the smaller is 27.5% of the larger (27.5 = 100 x 0.275).

Example of the use of the tables: −52 dB is sometimes considered the limit of tolerable cross-modulation. What is the corresponding percent cross-modulation? Using Chart V1 and Table V5, the voltage ratio corresponding to −52dB is 0.0025. So the answer is 100 x 0.0025 = **0.25%.**

3. **Relation between dBmV and mV:** The voltage ratio between any given voltage and one millivolt is that voltage expressed in millivolts. Thus the voltage vs. db charts and tables can be used directly to find dBmV when voltage is known or vice versa.

Example: What dBmV level corresponds to 33.2 microvolts across 75 ohms? Use Chart V1 and Table V4. 33.2 microvolts is 0.0332 millivolts $\left(\text{millivolts} = \frac{\text{microvolts}}{1000}\right)$. dB corresponding to a voltage ratio of 0.0332 is −29.577 dB, so the answer is **−29.577 dB.**

Example of a reverse case: Find the voltage corresponding to +17.21 dBmV. From chart V2 and table V7, 17.21 dB corresponds to a voltage ratio of 7.261, so the answer is **7.261 millivolts.**

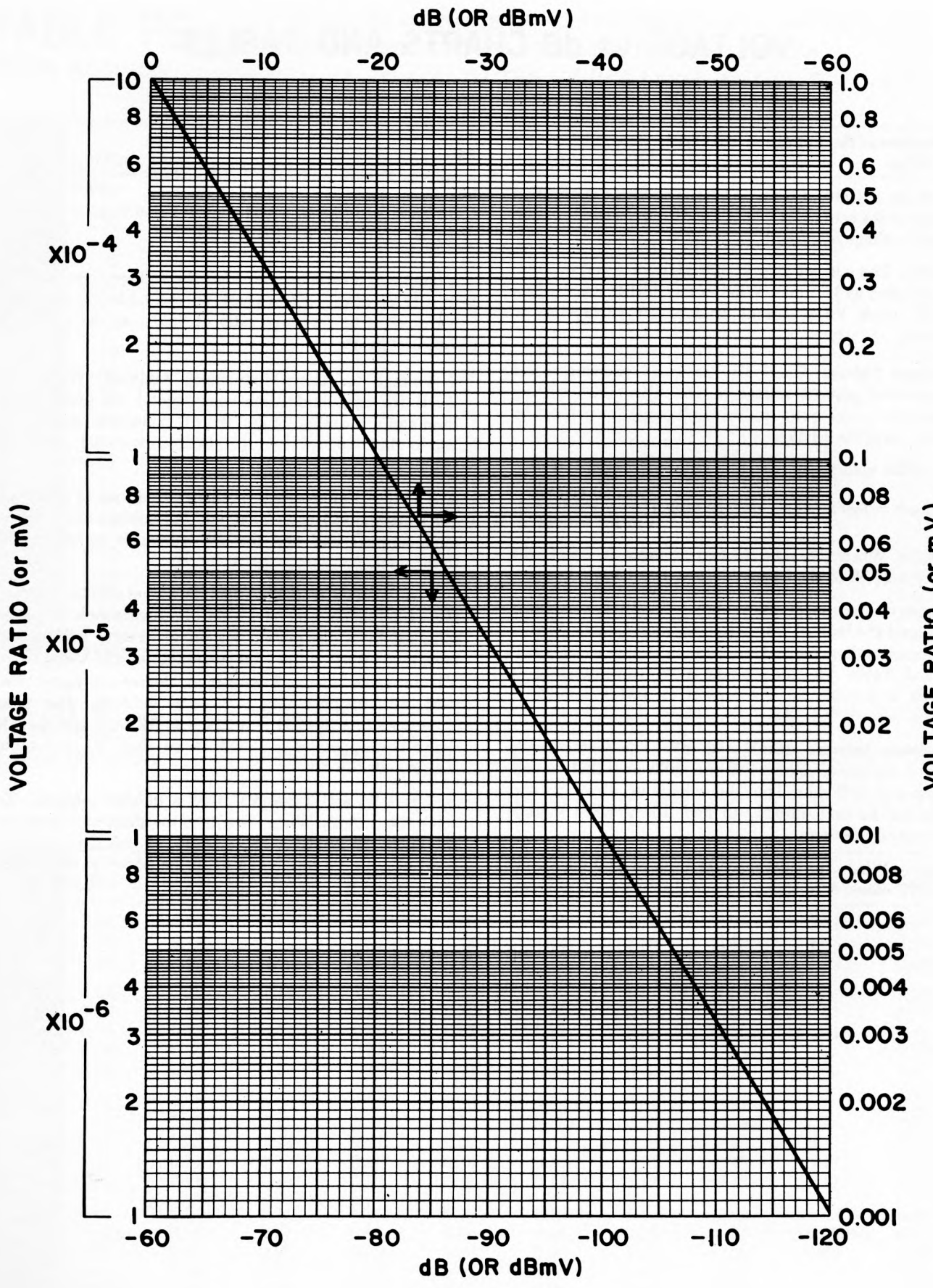
4. **Voltage (or Cross-Modulation) Addition** When two levels (or cross-modulation components) are given in dB form and it is desired to find the dB expression corresponding to their voltage sum (or total cross-mod.) either of two procedures may be used:

a. The direct approach is to change each one to a voltage (or % cross-mod.) expression, add the voltages (or % cross-mod. figures) and find the dB expression corresponding to the total.

For example: At its normal operating level a trunk line system of amplifiers generates −58 dB cross-modulation. It is followed by a distribution system generating −53 dB of cross-mod. What is the total cross-mod. in dB? Using chart V1 and table V5 the % cross-mod. figures are found. For −58 dB: 0.1259%. For −53 dB: 0.2239%. The total % cross mod. is 0.1259 + 0.2239 = 0.3498% and the dB figure corresponding to 0.35% (from chart V1 and table V4) is **−49.119 dB.**

b. **Chart V3 and Table V8 allow a quicker solution** To solve the problem above, first take the difference between the given dB levels: −58 − (−53) = −5 dB. Opposite 5 dB in table V8 find 3.874 dB to be added to the higher level, which is −53 dB. −53 + 3.874 = **−49.126 dB.**

CHART V1 (VOLTAGE RATIO)



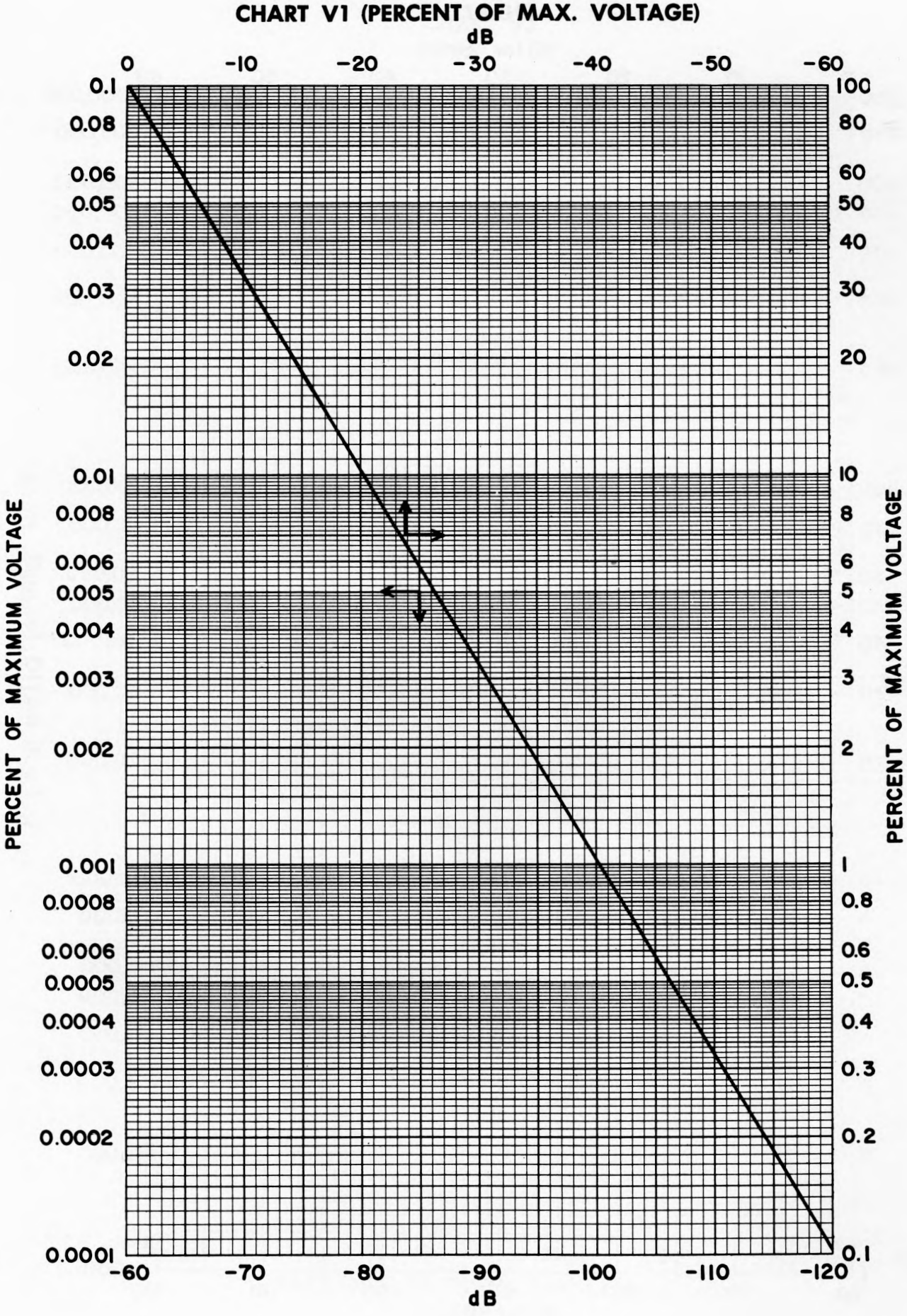


CHART V1 (PERCENT OF MAX. VOLTAGE)
dB
0
-10
-20
-30
-40
-50
-60
0.1
0.08
0.06
0.05
0.04
0.03
0.02
0.01
0.008
0.006
0.005
0.004
0.003
0.002
0.001
0.0008
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1
0.8
0.6
0.5
0.4
0.3
0.2
0.1
PERCENT OF MAXIMUM VOLTAGE
PERCENT OF MAXIMUM VOLTAGE
-60
-70
-80
-90
-100
-110
-120
dB

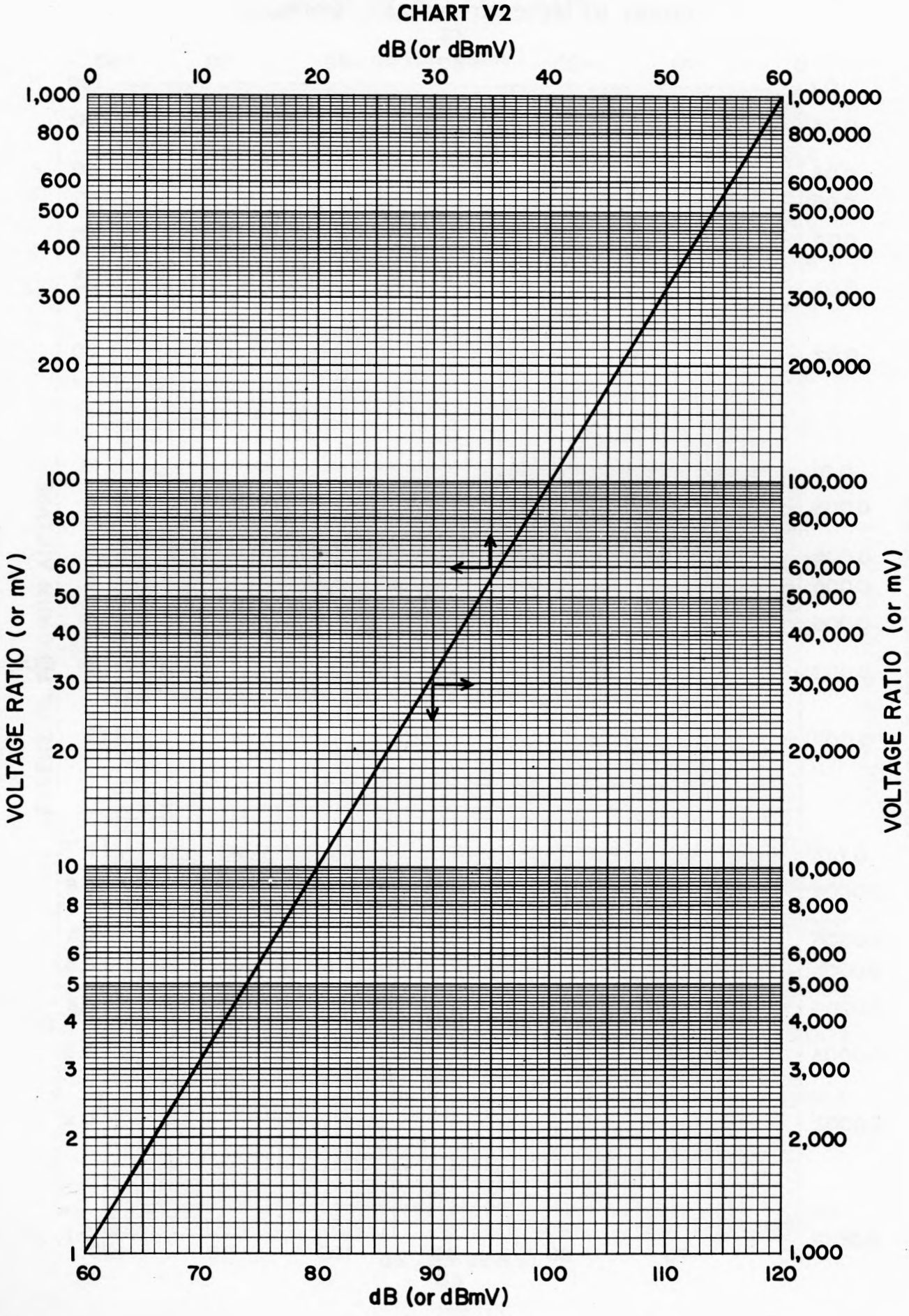


CHART V2
dB (or dBmV)
0
10
20
30
40
50
60
1,000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1
VOLTAGE RATIO (or mV)
1,000,000
800,000
600,000
500,000
400,000
300,000
200,000
100,000
80,000
60,000
50,000
40,000
30,000
20,000
10,000
8,000
6,000
5,000
4,000
3,000
2,000
1,000
VOLTAGE RATIO (or mV)
60
70
80
90
100
110
120
dB (or dBmV)

CHART V3

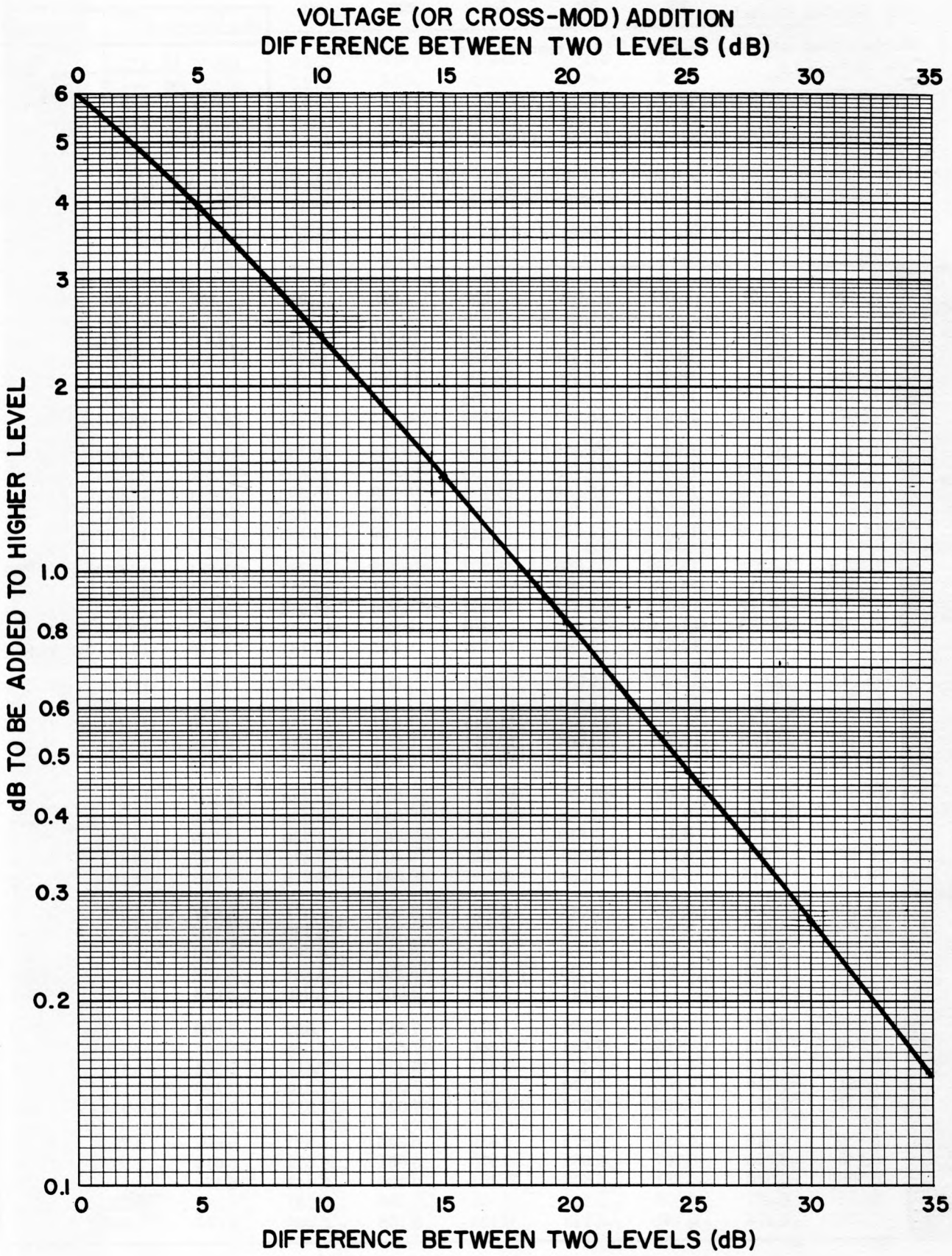

VOLTAGE (OR CROSS-MOD) ADDITION
DIFFERENCE BETWEEN TWO LEVELS (dB)
0
5
10
15
20
25
30
35
6
5
4
3
2
1.0
0.8
0.6
0.5
0.4
0.3
0.2
0.1
dB TO BE ADDED TO HIGHER LEVEL
DIFFERENCE BETWEEN TWO LEVELS (dB)

TABLE V4

GIVEN: VOLTAGE RATIO (or MILLIVOLTS) (0.1 to 1.0); FIND: −dB (or −dBmV) (−20 to 0)

For voltage ratios less than 0.1:

1. Multiply given ratio by a multiple of 10 as required to give a number between 0.1 and 1.0.
2. Look up −dB corresponding to this number in Table V4.
3. Add to the result −dBs corresponding to the multiple of 10 used in step 1.

For Multiple of 10	Add −dBs
10	−20
100	−40
1000	−60
10,000	−80

EXAMPLE: Given voltage ratio = 0.000172. Multiplying by 1000 we get 0.172. From Table V4, 0.172 corresponds to −15.289 dB. Adding −60 dB corresponding to the multiple used, we get −15.289 + (−60) = **−75.289 dB.**

NOTE: The minus signs in front of all dB numbers in this table have been omitted!

Voltage Ratio	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.10	20.000	19.914	19.828	19.743	19.659	19.576	19.494	19.412	19.332	19.251
.11	19.172	19.094	19.016	18.938	18.862	18.786	18.711	18.636	18.562	18.439
.12	18.416	18.344	18.273	18.202	18.132	18.062	17.993	17.924	17.856	17.788
.13	17.721	17.655	17.589	17.523	17.458	17.393	17.329	17.266	17.202	17.140
.14	17.077	17.016	16.954	16.893	16.833	16.773	16.713	16.654	16.595	16.536
.15	16.478	16.420	16.363	16.306	16.250	16.193	16.138	16.082	16.027	15.972
.16	15.918	15.863	15.810	15.756	15.703	15.650	15.598	15.546	15.494	15.442
.17	15.391	15.340	15.289	15.239	15.189	15.139	15.090	15.041	14.992	14.943
.18	14.895	14.846	14.799	14.751	14.704	14.657	14.610	14.563	14.517	14.471
.19	14.425	14.379	14.334	14.289	14.244	14.199	14.155	14.111	14.067	14.023
.20	13.979	13.936	13.893	13.850	13.807	13.765	13.723	13.681	13.639	13.597
.21	13.556	13.514	13.473	13.432	13.392	13.351	13.311	13.271	13.231	13.191
.22	13.152	13.112	13.073	13.034	12.992	12.956	12.918	12.879	12.841	12.803
.23	12.765	12.728	12.690	12.653	12.616	12.579	12.542	12.505	12.468	12.432
.24	12.396	12.360	12.324	12.288	12.252	12.217	12.181	12.146	12.111	12.076
.25	12.041	12.007	11.972	11.938	11.903	11.869	11.835	11.801	11.768	11.734
.26	11.701	11.667	11.634	11.601	11.568	11.535	11.502	11.470	11.437	11.405
.27	11.373	11.341	11.309	11.277	11.245	11.213	11.182	11.150	11.119	11.088
.28	11.057	11.026	10.995	10.964	10.934	10.903	10.873	10.842	10.812	10.782
.29	10.752	10.722	10.692	10.663	10.633	10.604	10.574	10.545	10.516	10.487
.30	10.458	10.429	10.400	10.371	10.343	10.314	10.286	10.257	10.229	10.201
.31	10.173	10.145	10.117	10.089	10.061	10.034	10.006	9.979	9.951	9.924
.32	9.897	9.870	9.843	9.816	9.789	9.762	9.736	9.709	9.683	9.656
.33	9.630	9.603	9.577	9.551	9.525	9.499	9.473	9.447	9.422	9.396
.34	9.370	9.345	9.319	9.294	9.269	9.244	9.218	9.193	9.169	9.143
.35	9.119	9.094	9.069	9.045	9.020	8.995	8.971	8.947	8.922	8.898
.36	8.874	8.850	8.826	8.802	8.778	8.754	8.730	8.707	8.683	8.659
.37	8.636	8.603	8.589	8.566	8.543	8.519	8.496	8.473	8.450	8.427
.38	8.404	8.383	8.359	8.336	8.313	8.291	8.268	8.246	8.223	8.201
.39	8.179	8.156	8.134	8.112	8.090	8.068	8.046	8.024	8.002	7.991
.40	7.959	7.937	7.915	7.894	7.872	7.851	7.829	7.808	7.787	7.766
.41	7.744	7.723	7.702	7.681	7.660	7.639	7.618	7.597	7.576	7.556
.42	7.535	7.514	7.494	7.473	7.453	7.432	7.412	7.391	7.371	7.351
.43	7.331	7.310	7.290	7.270	7.250	7.230	7.210	7.190	7.171	7.151
.44	7.131	7.111	7.092	7.072	7.052	7.033	7.013	6.994	6.974	6.955
.45	6.936	6.916	6.897	6.878	6.859	6.840	6.821	6.802	6.783	6.764
.46	6.745	6.726	6.707	6.688	6.670	6.651	6.632	6.614	6.595	6.577
.47	6.558	6.540	6.521	6.503	6.484	6.466	6.448	6.430	6.411	6.393
.48	6.375	6.357	6.339	6.321	6.303	6.285	6.267	6.249	6.232	6.212
.49	6.196	6.178	6.161	6.143	6.125	6.108	6.090	6.073	6.055	6.038

TABLE V4 continued

Voltage Ratio	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.50	6.021	6.003	5.986	5.969	5.951	5.934	5.917	5.900	5.883	5.866
.51	5.849	5.832	5.815	5.798	5.781	5.764	5.747	5.730	5.713	5.697
.52	5.680	5.663	5.647	5.630	5.613	5.597	5.580	5.564	5.547	5.531
.53	5.514	5.498	5.482	5.465	5.449	5.433	5.417	5.401	5.384	5.368
.54	5.352	5.336	5.320	5.304	5.288	5.272	5.256	5.240	5.224	5.209
.55	5.193	5.177	5.161	5.145	5.130	5.114	5.098	5.083	5.067	5.052
.56	5.036	5.021	5.005	4.990	4.974	4.959	4.944	4.928	4.913	4.898
.57	4.883	4.867	4.852	4.837	4.822	4.807	4.792	4.776	4.761	4.746
.58	4.731	4.716	4.702	4.687	4.672	4.657	4.642	4.627	4.612	4.598
.59	4.583	4.568	4.554	4.539	4.524	4.510	4.495	4.481	4.466	4.451
.60	4.437	4.423	4.408	4.394	4.379	4.365	4.351	4.336	4.322	4.308
.61	4.293	4.279	4.265	4.251	4.237	4.222	4.208	4.194	4.180	4.166
.62	4.152	4.138	4.124	4.110	4.096	4.082	4.069	4.055	4.041	4.027
.63	4.013	3.999	3.986	3.972	3.958	3.945	3.931	3.917	3.904	3.890
.64	3.876	3.863	3.849	3.836	3.822	3.809	3.795	3.782	3.768	3.755
.65	3.742	3.728	3.715	3.702	3.688	3.675	3.662	3.649	3.635	3.622
.66	3.609	3.596	3.583	3.570	3.557	3.544	3.531	3.517	3.504	3.491
.67	3.479	3.466	3.453	3.440	3.427	3.414	3.401	3.388	3.375	3.363
.68	3.350	3.337	3.324	3.312	3.299	3.286	3.274	3.261	3.248	3.236
.69	3.223	3.210	3.198	3.185	3.173	3.160	3.148	3.135	3.123	3.110
.70	3.098	3.086	3.073	3.061	3.049	3.036	3.024	3.012	2.999	2.987
.71	2.975	2.963	2.950	2.938	2.926	2.914	2.902	2.890	2.878	2.865
.72	2.853	2.841	2.829	2.817	2.805	2.793	2.781	2.769	2.757	2.745
.73	2.734	2.722	2.710	2.698	2.868	2.674	2.662	2.651	2.639	2.627
.74	2.615	2.604	2.592	2.580	2.569	2.557	2.545	2.534	2.522	2.510
.75	2.499	2.487	2.476	2.464	2.453	2.441	2.430	2.418	2.407	2.395
.76	2.384	2.372	2.361	2.350	2.338	2.327	2.315	2.304	2.293	2.281
.77	2.270	2.259	2.248	2.236	2.225	2.214	2.203	2.192	2.180	2.169
.78	2.158	2.147	2.136	2.125	2.114	2.103	2.092	2.081	2.069	2.058
.79	2.047	2.036	2.025	2.015	2.004	1.993	1.982	1.971	1.960	1.949
.80	1.938	1.927	1.917	1.906	1.894	1.884	1.873	1.863	1.852	1.841
.81	1.830	1.820	1.809	1.798	1.788	1.777	1.766	1.756	1.745	1.734
.82	1.724	1.713	1.703	1.692	1.681	1.671	1.660	1.650	1.639	1.629
.83	1.618	1.608	1.598	1.587	1.577	1.566	1.556	1.545	1.535	1.525
.84	1.514	1.504	1.494	1.483	1.473	1.463	1.453	1.442	1.432	1.422
.85	1.412	1.401	1.391	1.381	1.371	1.361	1.351	1.340	1.330	1.320
.86	1.310	1.300	1.290	1.280	1.270	1.260	1.250	1.240	1.230	1.220
.87	1.210	1.200	1.190	1.180	1.170	1.160	1.150	1.140	1.130	1.120
.88	1.110	1.100	1.091	1.081	1.071	1.061	1.051	1.042	1.032	1.022
.89	1.012	1.002	.993	.983	.973	.964	.954	.944	.934	.925
.90	.915	.906	.896	.886	.877	.867	.857	.848	.838	.829
.91	.819	.810	.800	.791	.781	.772	.762	.753	.743	.734
.92	.724	.715	.705	.696	.687	.677	.668	.658	.649	.640
.93	.630	.621	.612	.602	.593	.584	.574	.565	.556	.547
.94	.537	.528	.519	.510	.501	.491	.482	.473	.464	.455
.95	.446	.436	.427	.418	.409	.400	.391	.382	.373	.364
.96	.355	.346	.336	.327	.318	.309	.300	.291	.282	.274
.97	.265	.256	.247	.238	.229	.220	.211	.202	.193	.184
.98	.175	.167	.158	.149	.140	.131	.122	.114	.105	.096
.99	.087	.079	.070	.061	.052	.044	.035	.026	.017	.009

TABLE V5

GIVEN: −dB (or −dBmV) (0 to −20);
FIND: VOLTAGE RATIO (or mV) (1.0 to 0.1)

For − db below −20:

1. Add dBs (in multiples of 20) as required to give a number between 0 and −20.
2. Look up voltage ratio corresponding to this number in table V5.
3. Multiply the voltage ratio found by the number corresponding to the dBs added in step 1.

For dBs Added	Multiply By
20	0.1
40	0.01
60	0.001
80	0.0001

EXAMPLE: Given −53.22 dB. Adding 40 dB we get −13.22 dB. From Table V5, voltage ratio corresponding to −13.22 dB is 0.2183. Multiplying by 0.01 (corresponding to 40 dB added) we get 0.2183 x 0.01 = **0.002183.**

dB	0.00	0.02	0.04	0.06	0.08
0.0	1.0000	.9977	.9954	.9931	.9908
−0.1	.9886	.9863	.9840	.9817	.9795
−0.2	.9772	.9750	.9727	.9705	.9683
−0.3	.9661	.9638	.9616	.9594	.9572
−0.4	.9550	.9528	.9506	.9484	.9462
−0.5	.9441	.9419	.9397	.9376	.9354
−0.6	.9333	.9311	.9290	.9268	.9247
−0.7	.9226	.9204	.9183	.9162	.9141
−0.8	.9120	.9099	.9078	.9057	.9036
−0.9	.9016	.8995	.8974	.8954	.8933
−1.0	.8913	.8892	.8872	.8851	.8831
−1.1	.8810	.8790	.8770	.8750	.8730
−1.2	.8710	.8690	.8670	.8650	.8630
−1.3	.8610	.8590	.8570	.8551	.8531
−1.4	.8511	.8492	.8472	.8453	.8433
−1.5	.8414	.8395	.8375	.8356	.8337
−1.6	.8318	.8299	.8279	.8260	.8241
−1.7	.8222	.8204	.8185	.8166	.8147
−1.8	.8128	.8110	.8091	.8072	.8054
−1.9	.8035	.8017	.7998	.7980	.7962
−2.0	.7943	.7925	.7907	.7889	.7870
−2.1	.7852	.7834	.7816	.7798	.7780
−2.2	.7762	.7745	.7727	.7709	.7691
−2.3	.7674	.7656	.7638	.7621	.7603
−2.4	.7586	.7568	.7551	.7534	.7516
−2.5	.7499	.7482	.7464	.7447	.7430
−2.6	.7413	.7396	.7379	.7362	.7345
−2.7	.7328	.7311	.7295	.7278	.7261
−2.8	.7244	.7228	.7211	.7194	.7178
−2.9	.7161	.7145	.7129	.7112	.7096
−3.0	.7079	.7063	.7047	.7031	.7015
−3.1	.6998	.6982	.6966	.6950	.6934
−3.2	.6918	.6902	.6887	.6871	.6855
−3.3	.6839	.6823	.6808	.6792	.6776
−3.4	.6761	.6745	.6730	.6714	.6699
−3.5	.6683	.6668	.6653	.6637	.6622
−3.6	.6607	.6592	.6577	.6561	.6546
−3.7	.6531	.6516	.6501	.6486	.6471
−3.8	.6457	.6442	.6427	.6412	.6397
−3.9	.6383	.6368	.6353	.6339	.6324

dB	0.00	0.02	0.04	0.06	0.08
−4.0	.6310	.6295	.6281	.6266	.6252
−4.1	.6237	.6223	.6209	.6194	.6180
−4.2	.6166	.6152	.6139	.6124	.6109
−4.3	.6095	.6081	.6067	.6053	.6039
−4.4	.6026	.6012	.5998	.5984	.5970
−4.5	.5957	.5943	.5929	.5916	.5902
−4.6	.5888	.5875	.5861	.5848	.5834
−4.7	.5821	.5808	.5794	.5781	.5768
−4.8	.5754	.5741	.5728	.5715	.5702
−4.9	.5689	.5675	.5662	.5649	.5636
−5.0	.5623	.5610	.5598	.5585	.5572
−5.1	.5559	.5546	.5534	.5521	.5508
−5.2	.5495	.5483	.5470	.5458	.5445
−5.3	.5433	.5420	.5408	.5395	.5383
−5.4	.5370	.5358	.5346	.5333	.5321
−5.5	.5309	.5297	.5284	.5272	.5260
−5.6	.5248	.5236	.5224	.5212	.5200
−5.7	.5188	.5176	.5164	.5152	.5140
−5.8	.5129	.5117	.5105	.5093	.5082
−5.9	.5070	.5058	.5047	.5035	.5023
−6.0	.5012	.5000	.4989	.4977	.4966
−6.1	.4955	.4943	.4932	.4920	.4909
−6.2	.4898	.4887	.4875	.4864	.4853
−6.3	.4842	.4831	.4819	.4808	.4797
−6.4	.4786	.4775	.4764	.4753	.4742
−6.5	.4732	.4721	.4710	.4699	.4688
−6.6	.4677	.4667	.4656	.4645	.4634
−6.7	.4624	.4613	.4603	.4592	.4581
−6.8	.4571	.4560	.4550	.4539	.4529
−6.9	.4519	.4508	.4498	.4487	.4477
−7.0	.4467	.4457	.4446	.4436	.4426
−7.1	.4416	.4406	.4395	.4385	.4375
−7.2	.4365	.4355	.4345	.4335	.4325
−7.3	.4315	.4305	.4295	.4285	.4276
−7.4	.4266	.4256	.4246	.4236	.4227
−7.5	.4217	.4207	.4198	.4188	.4178
−7.6	.4169	.4159	.4150	.4140	.4130
−7.7	.4121	.4111	.4102	.4093	.4083
−7.8	.4074	.4064	.4055	.4046	.4036
−7.9	.4027	.4018	.4009	.3999	.3990

TABLE V5 continued

dB	0.00	0.02	0.04	0.06	0.08
− 8.0	.3981	.3972	.3963	.3954	.3945
− 8.1	.3936	.3926	.3917	.3908	.3899
− 8.2	.3890	.3882	.3873	.3864	.3855
− 8.3	.3846	.3837	.3828	.3819	.3811
− 8.4	.3802	.3793	.3784	.3776	.3767
− 8.5	.3758	.3750	.3741	.3733	.3724
− 8.6	.3715	.3707	.3698	.3690	.3681
− 8.7	.3673	.3664	.3656	.3648	.3639
− 8.8	.3631	.3622	.3614	.3606	.3597
− 8.9	.3589	.3581	.3573	.3565	.3556
− 9.0	.3548	.3540	.3532	.3524	.3516
− 9.1	.3508	.3499	.3491	.3483	.3475
− 9.2	.3467	.3459	.3451	.3443	.3436
− 9.3	.3428	.3420	.3412	.3404	.3396
− 9.4	.3388	.3381	.3373	.3365	.3357
− 9.5	.3350	.3342	.3334	.3327	.3319
− 9.6	.3311	.3304	.3296	.3289	.3281
− 9.7	.3273	.3266	.3258	.3251	.3243
− 9.8	.3236	.3228	.3221	.3214	.3206
− 9.9	.3199	.3192	.3184	.3177	.3170
−10.0	.3162	.3155	.3148	.3141	.3133
−10.1	.3126	.3119	.3112	.3105	.3097
−10.2	.3090	.3083	.3076	.3069	.3062
−10.3	.3055	.3048	.3041	.3034	.3027
−10.4	.3020	.3013	.3006	.2999	.2992
−10.5	.2985	.2979	.2972	.2965	.2958
−10.6	.2951	.2944	.2938	.2931	.2924
−10.7	.2917	.2911	.2904	.2897	.2891
−10.8	.2884	.2877	.2871	.2864	.2858
−10.9	.2851	.2844	.2838	.2831	.2825
−11.0	.2818	.2812	.2805	.2799	.2793
−11.1	.2786	.2780	.2773	.2767	.2761
−11.2	.2754	.2748	.2742	.2735	.2729
−11.3	.2723	.2716	.2710	.2704	.2698
−11.4	.2692	.2685	.2679	.2673	.2667
−11.5	.2661	.2655	.2649	.2642	.2636
−11.6	.2630	.2624	.2618	.2612	.2606
−11.7	.2600	.2594	.2588	.2582	.2576
−11.8	.2570	.2564	.2559	.2553	.2547
−11.9	.2541	.2535	.2529	.2523	.2518
−12.0	.2512	.2506	.2500	.2495	.2489
−12.1	.2483	.2477	.2472	.2466	.2460
−12.2	.2455	.2449	.2443	.2438	.2432
−12.3	.2427	.2421	.2415	.2410	.2404
−12.4	.2399	.2393	.2388	.2382	.2377
−12.5	.2371	.2366	.2360	.2355	.2350
−12.6	.2344	.2339	.2333	.2328	.2323
−12.7	.2317	.2312	.2307	.2301	.2296
−12.8	.2291	.2286	.2280	.2275	.2270
−12.9	.2265	.2259	.2254	.2249	.2244
−13.0	.2239	.2234	.2228	.2223	.2218
−13.1	.2213	.2208	.2203	.2198	.2193
−13.2	.2188	.2183	.2178	.2173	.2168
−13.3	.2163	.2158	.2153	.2148	.2143
−13.4	.2138	.2133	.2128	.2123	.2118
−13.5	.2113	.2109	.2104	.2099	.2094
−13.6	.2089	.2084	.2080	.2075	.2070
−13.7	.2065	.2061	.2056	.2051	.2046
−13.8	.2042	.2037	.2032	.2028	.2023
−13.9	.2018	.2014	.2009	.2004	.2000

dB	0.00	0.02	0.04	0.06	0.08
−14.0	.1995	.1991	.1986	.1982	.1977
−14.1	.1972	.1968	.1963	.1959	.1954
−14.2	.1950	.1945	.1941	.1936	.1932
−14.3	.1928	.1923	.1919	.1914	.1910
−14.4	.1905	.1901	.1897	.1892	.1888
−14.5	.1884	.1879	.1875	.1871	.1866
−14.6	.1862	.1858	.1854	.1849	.1845
−14.7	.1841	.1837	.1832	.1828	.1824
−14.8	.1820	.1816	.1811	.1807	.1803
−14.9	.1799	.1795	.1791	.1786	.1782
−15.0	.1778	.1774	.1770	.1766	.1762
−15.1	.1758	.1754	.1750	.1746	.1742
−15.2	.1738	.1734	.1730	.1726	.1722
−15.3	.1718	.1714	.1710	.1706	.1702
−15.4	.1698	.1694	.1690	.1687	.1683
−15.5	.1679	.1675	.1671	.1667	.1663
−15.6	.1660	.1656	.1652	.1648	.1644
−15.7	.1641	.1637	.1633	.1629	.1626
−15.8	.1622	.1618	.1614	.1611	.1607
−15.9	.1603	.1600	.1596	.1592	.1589
−16.0	.1585	.1581	.1578	.1574	.1570
−16.1	.1567	.1563	.1560	.1556	.1552
−16.2	.1549	.1545	.1542	.1538	.1535
−16.3	.1531	.1528	.1524	.1521	.1517
−16.4	.1514	.1510	.1507	.1503	.1500
−16.5	.1496	.1493	.1489	.1486	.1483
−16.6	.1479	.1476	.1472	.1469	.1466
−16.7	.1462	.1459	.1455	.1452	.1449
−16.8	.1445	.1442	.1439	.1435	.1432
−16.9	.1429	.1426	.1422	.1419	.1416
−17.0	.1413	.1409	.1406	.1403	.1400
−17.1	.1396	.1393	.1390	.1387	.1384
−17.2	.1380	.1377	.1374	.1371	.1368
−17.3	.1365	.1361	.1358	.1355	.1352
−17.4	.1349	.1346	.1343	.1340	.1337
−17.5	.1334	.1330	.1327	.1324	.1321
−17.6	.1318	.1315	.1312	.1309	.1306
−17.7	.1303	.1300	.1297	.1294	.1291
−17.8	.1288	.1285	.1282	.1279	.1276
−17.9	.1274	.1271	.1268	.1265	.1262
−18.0	.1259	.1256	.1253	.1250	.1247
−18.1	.1245	.1242	.1239	.1236	.1233
−18.2	.1230	.1227	.1225	.1222	.1219
−18.3	.1216	.1213	.1211	.1208	.1205
−18.4	.1202	.1199	.1197	.1194	.1191
−18.5	.1189	.1186	.1183	.1180	.1178
−18.6	.1175	.1172	.1169	.1167	.1164
−18.7	.1161	.1159	.1156	.1153	.1151
−18.8	.1148	.1146	.1143	.1140	.1138
−18.9	.1135	.1132	.1130	.1127	.1125
−19.0	.1122	.1119	.1117	.1114	.1112
−19.1	.1109	.1107	.1104	.1102	.1099
−19.2	.1096	.1094	.1091	.1089	.1086
−19.3	.1084	.1081	.1079	.1076	.1074
−19.4	.1072	.1069	.1067	.1064	.1062
−19.5	.1059	.1057	.1054	.1052	.1050
−19.6	.1047	.1045	.1042	.1040	.1038
−19.7	.1035	.1033	.1030	.1028	.1026
−19.8	.1023	.1021	.1019	.1016	.1014
−19.9	.1012	.1009	.1007	.1005	.1002
−20.0	.1000	.0998	.0995	.0993	.0991

TABLE V6

GIVEN: VOLTAGE RATIO (or mV) (1.0 to 10.0); FIND: +dB (or +dBmV) (0 to +20)

For voltage ratio greater than 10:

1. Divide by the multiple of 10 required to give a number between 1.0 and 10.0.
2. Look up +dB corresponding to this number in table V6.
3. Add to the result the number of dBs corresponding to the multiple of 10 used in step 1.

For Multiple of 10	Add dBs
10	20
100	40
1000	60
10,000	80

EXAMPLE: Given voltage ratio = 65,200. Dividing by 10,000 we get 6.52. From table V6, dBs corresponding to 6.52 is 16.285. Adding the number of dBs according to divisor used in step 3 we get 16,285 + 80 = **+96.285 dB.**

Voltage Ratio	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
1.0	.000	.086	.172	.257	.341	.424	.506	.588	.668	.749
1.1	.828	.906	.984	1.062	1.138	1.214	1.289	1.364	1.438	1.511
1.2	1.584	1.656	1.727	1.798	1.868	1.938	1.007	2.076	2.144	2.212
1.3	2.279	2.345	2.411	2.477	2.542	2.607	2.671	2.734	2.798	2.860
1.4	2.923	2.984	3.046	3.107	3.167	3.227	3.287	3.346	3.405	3.464
1.5	3.522	3.580	3.637	3.694	3.750	3.807	3.862	3.918	3.973	4.028
1.6	4.082	4.137	4.190	4.244	4.297	4.350	4.402	4.454	4.506	4.558
1.7	4.609	4.660	4.711	4.761	4.811	4.861	4.910	4.959	5.008	5.057
1.8	5.105	5.154	5.201	5.249	5.296	5.343	5.390	5.437	5.483	5.529
1.9	5.575	5.621	5.666	5.711	5.756	5.801	5.845	5.889	5.933	5.977
2.0	6.021	6.064	6.107	6.150	6.193	6.235	6.277	6.319	6.361	6.403
2.1	6.444	6.486	6.527	6.568	6.608	6.649	6.689	6.729	6.769	6.809
2.2	6.848	6.888	6.927	6.966	7.008	7.044	7.082	7.121	7.159	7.197
2.3	7.235	7.272	7.310	7.347	7.384	7.421	7.458	7.495	7.532	7.568
2.4	7.604	7.640	7.676	7.712	7.748	7.783	7.819	7.854	7.889	7.924
2.5	7.959	7.993	8.028	8.062	8.097	8.131	8.165	8.199	8.232	8.266
2.6	8.299	8.333	8.366	8.399	8.432	8.465	8.498	8.530	8.563	8.595
2.7	8.627	8.659	8.691	8.723	8.755	8.787	8.818	8.850	8.881	8.912
2.8	8.943	8.974	9.005	9.036	9.066	9.097	9.127	9.158	9.188	9.218
2.9	9.248	9.278	9.308	9.337	9.367	9.396	9.426	9.455	9.484	9.513
3.0	9.542	9.571	9.600	9.629	9.657	9.686	9.714	9.743	9.771	9.799
3.1	9.827	9.855	9.883	9.911	9.939	9.966	9.994	10.021	10.049	10.076
3.2	10.103	10.130	10.157	10.184	10.211	10.238	10.264	10.291	10.317	10.344
3.3	10.370	10.397	10.423	10.449	10.475	10.501	10.527	10.553	10.578	10.604
3.4	10.630	10.655	10.681	10.706	10.731	10.756	10.782	10.807	10.832	10.857
3.5	10.881	10.906	10.931	10.955	10.980	11.005	11.029	11.053	11.078	11.102
3.6	11.126	11.150	11.174	11.198	11.222	11.246	11.270	11.293	11.317	11.341
3.7	11.364	11.387	11.411	11.434	11.457	11.481	11.504	11.527	11.550	11.573
3.8	11.596	11.618	11.641	11.664	11.687	11.709	11.732	11.754	11.777	11.799
3.9	11.821	11.844	11.866	11.888	11.910	11.932	11.954	11.976	11.998	12.019
4.0	12.041	12.063	12.085	12.106	12.128	12.149	12.171	12.192	12.213	12.234
4.1	12.256	12.277	12.298	12.319	12.340	12.361	12.382	12.403	12.424	12.444
4.2	12.465	12.486	12.506	12.527	12.547	12.568	12.588	12.609	12.629	12.649
4.3	12.669	12.690	12.710	12.730	12.750	12.770	12.790	12.810	12.829	12.849
4.4	12.869	12.889	12.908	12.928	12.948	12.967	12.987	13.006	13.026	13.045
4.5	13.064	13.084	13.103	13.122	13.141	13.160	13.179	13.198	13.217	13.236
4.6	13.255	13.274	13.293	13.312	13.330	13.349	13.368	13.386	13.405	13.423
4.7	13.442	13.460	13.479	13.497	13.516	13.534	13.552	13.570	13.589	13.607
4.8	13.625	13.643	13.661	13.679	13.697	13.715	13.733	13.751	13.768	13.786
4.9	13.804	13.822	13.839	13.857	13.875	13.892	13.910	13.927	13.945	13.962

TABLE V6 continued

Voltage Ratio	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
5.0	13.979	13.997	14.014	14.031	14.049	14.066	14.083	14.100	14.117	14.134
5.1	14.151	14.168	14.185	14.202	14.219	14.236	14.253	14.270	14.287	14.303
5.2	14.320	14.337	14.353	14.370	14.387	14.403	14.420	14.436	14.453	14.469
5.3	14.486	14.502	14.518	14.535	14.551	14.567	14.583	14.599	14.616	14.632
5.4	14.648	14.664	14.680	14.696	14.712	14.728	14.744	14.760	14.776	14.791
5.5	14.807	14.823	14.839	14.855	14.870	14.886	14.902	14.917	14.933	14.948
5.6	14.964	14.979	14.995	15.010	15.026	15.041	15.056	15.072	15.087	15.102
5.7	15.117	15.133	15.148	15.163	15.178	15.193	15.208	15.224	15.239	15.254
5.8	15.269	15.284	15.298	15.313	15.328	15.343	15.358	15.373	15.388	15.402
5.9	15.417	15.432	15.446	15.461	15.476	15.490	15.505	15.519	15.534	15.549
6.0	15.563	15.577	15.592	15.606	15.621	15.635	15.649	15.664	15.678	15.692
6.1	15.707	15.721	15.735	15.749	15.763	15.778	15.792	15.806	15.820	15.834
6.2	15.848	15.862	15.876	15.890	15.904	15.918	15.931	15.945	15.959	15.973
6.3	15.987	16.001	16.014	16.028	16.042	16.055	16.069	16.083	16.096	16.110
6.4	16.124	16.137	16.151	16.164	16.178	16.191	16.205	16.218	16.232	16.245
6.5	16.258	16.272	16.285	16.298	16.312	16.325	16.338	16.351	16.365	16.378
6.6	16.391	16.404	16.417	16.430	16.443	16.456	16.469	16.483	16.496	16.509
6.7	16.521	16.534	16.547	16.560	16.573	16.586	16.599	16.612	16.625	16.637
6.8	16.650	16.663	16.676	16.688	16.701	16.714	16.726	16.739	16.752	16.764
6.9	16.777	16.790	16.802	16.815	16.827	16.840	16.852	16.865	16.877	16.890
7.0	16.902	16.914	16.927	16.939	16.951	16.964	16.976	16.988	17.001	17.013
7.1	17.025	17.037	17.050	17.062	17.074	17.086	17.098	17.110	17.122	17.135
7.2	17.147	17.159	17.171	17.183	17.195	17.207	17.219	17.231	17.243	17.255
7.3	17.266	17.278	17.290	17.302	17.314	17.326	17.338	17.349	17.361	17.373
7.4	17.385	17.396	17.408	17.420	17.431	17.443	17.455	17.466	17.478	17.490
7.5	17.501	17.513	17.524	17.536	17.547	17.559	17.570	17.582	17.593	17.605
7.6	17.616	17.628	17.639	17.650	17.662	17.673	17.685	17.696	17.707	17.719
7.7	17.730	17.741	17.752	17.764	17.775	17.786	17.797	17.808	17.820	17.831
7.8	17.842	17.853	17.864	17.875	17.886	17.897	17.908	17.919	17.931	17.942
7.9	17.953	17.964	17.975	17.985	17.996	18.007	18.018	18.029	18.040	18.051
8.0	18.062	18.073	18.083	18.094	18.105	18.116	18.127	18.137	18.148	18.159
8.1	18.170	18.180	18.191	18.202	18.212	18.223	18.234	18.244	18.255	18.266
8.2	18.276	18.287	18.297	18.308	18.319	18.329	18.340	18.350	18.361	18.371
8.3	18.382	18.392	18.402	18.413	18.423	18.434	18.444	18.455	18.465	18.475
8.4	18.486	18.496	18.506	18.517	18.527	18.537	18.547	18.558	18.568	18.578
8.5	18.588	18.599	18.609	18.619	18.629	18.639	18.649	18.660	18.670	18.680
8.6	18.690	18.700	18.710	18.720	18.730	18.740	18.750	18.760	18.770	18.780
8.7	18.790	18.800	18.810	18.820	18.830	18.840	18.850	18.860	18.870	18.880
8.8	18.890	18.900	18.909	18.919	18.929	18.939	18.949	18.958	18.968	18.978
8.9	18.988	18.998	19.007	19.017	19.027	19.036	19.046	19.056	19.066	19.075
9.0	19.085	19.094	19.104	19.114	19.123	19.133	19.143	19.152	19.162	19.171
9.1	19.181	19.190	19.200	19.209	19.219	19.228	19.238	19.247	19.257	19.226
9.2	19.276	19.285	19.295	19.304	19.313	19.323	19.332	19.342	19.351	19.360
9.3	19.370	19.379	19.388	19.398	19.407	19.416	19.426	19.435	19.444	19.453
9.4	19.463	19.472	19.481	19.490	19.499	19.509	19.518	19.527	19.536	19.545
9.5	19.554	19.564	19.573	19.582	19.591	19.600	19.609	19.618	19.627	19.636
9.6	19.645	19.654	19.664	19.673	19.682	19.691	19.700	19.709	19.718	19.726
9.7	19.735	19.744	19.753	19.762	19.771	19.780	19.789	19.798	19.807	19.816
9.8	19.825	19.833	19.842	19.851	19.860	19.869	19.878	19.886	19.895	19.904
9.9	19.913	19.921	19.930	19.939	19.948	19.956	19.965	19.974	19.983	19.991
10.0	20.000	20.009	20.017	20.026	20.035	20.043	20.052	20.061	20.069	20.078

TABLE V7

GIVEN: +dB (or +dBmV) (0 to +20);
FIND: VOLTAGE RATIO (or mV) (1.0 to 10.0)

For +dBs greater than +20:

1. Subtract the multiple of 20 dB required to give a number between 0 and +20.
2. Look up the voltage ratio corresponding to this number in table V7.
3. Multiply the ratio found by the number corresponding to the dBs subtracted in step 1.

For dBs Subtracted	Multiply By
20	10
40	100
60	1000
80	10,000

EXAMPLE: Given +49.72 dB. Subtracting 40 dB we get 9.72 dB. From table V7 the voltage ratio corresponding to 9.72 dB is 3.062. Multiplying by 100 (corresponding to 40 dB subtracted in step 1) we get a voltage ratio of 3.062 x 100 = **306.2.**

dB	0.00	0.02	0.04	0.06	0.08
0.0	1.000	1.002	1.005	1.007	1.009
0.1	1.012	1.014	1.016	1.019	1.021
0.2	1.023	1.026	1.028	1.030	1.033
0.3	1.035	1.038	1.040	1.042	1.045
0.4	1.047	1.050	1.052	1.054	1.057
0.5	1.059	1.062	1.064	1.067	1.069
0.6	1.072	1.074	1.076	1.079	1.081
0.7	1.084	1.086	1.089	1.091	1.094
0.8	1.096	1.099	1.102	1.104	1.107
0.9	1.109	1.112	1.114	1.117	1.119
1.0	1.122	1.125	1.127	1.130	1.132
1.1	1.135	1.138	1.140	1.143	1.146
1.2	1.148	1.151	1.153	1.156	1.159
1.3	1.161	1.164	1.167	1.169	1.172
1.4	1.175	1.178	1.180	1.183	1.186
1.5	1.189	1.191	1.194	1.197	1.199
1.6	1.202	1.205	1.208	1.211	1.213
1.7	1.216	1.219	1.222	1.225	1.227
1.8	1.230	1.233	1.236	1.239	1.242
1.9	1.245	1.247	1.250	1.253	1.256
2.0	1.259	1.262	1.265	1.268	1.271
2.1	1.274	1.276	1.279	1.282	1.285
2.2	1.288	1.291	1.294	1.297	1.300
2.3	1.303	1.306	1.309	1.312	1.315
2.4	1.318	1.321	1.324	1.327	1.330
2.5	1.334	1.337	1.340	1.343	1.346
2.6	1.349	1.352	1.355	1.358	1.361
2.7	1.365	1.368	1.371	1.374	1.377
2.8	1.380	1.384	1.387	1.390	1.393
2.9	1.396	1.400	1.403	1.406	1.409
3.0	1.413	1.416	1.419	1.422	1.426
3.1	1.429	1.432	1.435	1.439	1.442
3.2	1.445	1.449	1.452	1.455	1.459
3.3	1.462	1.466	1.469	1.472	1.476
3.4	1.479	1.483	1.486	1.489	1.493
3.5	1.496	1.500	1.503	1.507	1.510
3.6	1.514	1.517	1.521	1.524	1.528
3.7	1.531	1.535	1.538	1.542	1.545
3.8	1.549	1.552	1.556	1.560	1.563
3.9	1.567	1.570	1.574	1.578	1.581

dB	0.00	0.02	0.04	0.06	0.08
4.0	1.585	1.589	1.592	1.596	1.600
4.1	1.603	1.607	1.611	1.614	1.618
4.2	1.622	1.626	1.629	1.633	1.637
4.3	1.641	1.644	1.648	1.652	1.656
4.4	1.660	1.663	1.667	1.671	1.675
4.5	1.679	1.683	1.687	1.690	1.694
4.6	1.698	1.702	1.706	1.710	1.714
4.7	1.718	1.722	1.726	1.730	1.734
4.8	1.738	1.742	1.746	1.750	1.754
4.9	1.758	1.762	1.766	1.770	1.774
5.0	1.778	1.782	1.786	1.791	1.795
5.1	1.799	1.803	1.807	1.811	1.816
5.2	1.820	1.824	1.828	1.832	1.837
5.3	1.841	1.845	1.849	1.854	1.858
5.4	1.862	1.866	1.871	1.875	1.879
5.5	1.884	1.888	1.892	1.897	1.901
5.6	1.905	1.910	1.914	1.919	1.923
5.7	1.928	1.932	1.936	1.941	1.945
5.8	1.950	1.954	1.959	1.963	1.968
5.9	1.972	1.977	1.982	1.986	1.991
6.0	1.995	2.000	2.004	2.009	2.014
6.1	2.018	2.023	2.028	2.032	2.037
6.2	2.042	2.046	2.051	2.056	2.061
6.3	2.065	2.070	2.075	2.080	2.084
6.4	2.089	2.094	2.099	2.104	1.109
6.5	2.113	2.118	2.123	2.128	2.133
6.6	2.138	2.143	2.148	2.153	2.158
6.7	2.163	2.168	2.173	2.178	2.183
6.8	2.188	2.193	2.198	2.203	2.208
6.9	2.213	2.218	2.223	2.228	2.234
7.0	2.239	2.244	2.249	2.254	2.259
7.1	2.265	2.270	2.275	2.280	2.286
7.2	2.291	2.296	2.301	2.307	2.312
7.3	2.317	2.323	2.328	2.333	2.339
7.4	2.344	2.350	2.355	2.360	2.366
7.5	2.371	2.377	2.382	2.388	2.393
7.6	2.399	2.404	2.410	2.415	2.421
7.7	2.427	2.432	2.438	2.443	2.449
7.8	2.455	2.460	2.466	2.472	2.477
7.9	2.483	2.489	2.495	2.500	2.506

TABLE V7 continued

dB	0.00	0.02	0.04	0.06	0.08
8.0	2.512	2.518	2.523	2.529	2.535
8.1	2.541	2.547	2.553	2.559	2.564
8.2	2.570	2.576	2.582	2.588	2.594
8.3	2.600	2.606	2.612	2.618	2.624
8.4	2.630	2.636	2.642	2.649	2.655
8.5	2.661	2.667	2.673	2.679	2.685
8.6	2.692	2.698	2.704	2.710	2.716
8.7	2.723	2.729	2.735	2.742	2.748
8.8	2.754	2.761	2.767	2.773	2.780
8.9	2.786	2.793	2.799	2.805	2.812
9.0	2.818	2.825	2.831	2.838	2.844
9.1	2.851	2.858	2.864	2.871	2.877
9.2	2.884	2.891	2.897	2.904	2.911
9.3	2.917	2.924	2.931	2.938	2.944
9.4	2.951	2.958	2.965	2.972	2.979
9.5	2.985	2.992	2.999	3.006	3.013
9.6	3.020	3.027	3.034	3.041	3.048
9.7	3.055	3.062	3.069	3.076	3.083
9.8	3.090	3.097	3.105	3.112	3.119
9.9	3.126	3.133	3.141	3.148	3.155
10.0	3.162	3.170	3.177	3.184	3.192
10.1	3.199	3.206	3.214	3.221	3.228
10.2	3.236	3.243	3.251	3.258	3.266
10.3	3.273	3.281	3.289	3.296	3.304
10.4	3.311	3.319	3.327	3.334	3.342
10.5	3.350	3.357	3.365	3.373	3.381
10.6	3.388	3.396	3.404	3.412	3.420
10.7	3.428	3.436	3.443	3.451	3.459
10.8	3.467	3.475	3.483	3.491	3.499
10.9	3.508	3.516	3.524	3.532	3.540
11.0	3.548	3.556	3.565	3.573	3.581
11.1	3.589	3.597	3.606	3.614	3.622
11.2	3.631	3.639	3.648	3.656	3.664
11.3	3.673	3.681	3.690	3.698	3.707
11.4	3.715	3.724	3.733	3.741	3.750
11.5	3.758	3.767	3.776	3.784	3.793
11.6	3.802	3.811	3.819	3.828	3.837
11.7	2.846	3.855	3.964	3.873	3.882
11.8	3.890	3.899	3.908	3.917	3.926
11.9	3.936	3.945	3.954	3.963	3.972
12.0	3.981	3.990	3.999	4.009	4.018
12.1	4.027	4.036	4.046	4.055	4.064
12.2	4.074	4.083	4.093	4.102	4.111
12.3	4.121	4.130	4.140	4.150	4.159
12.4	4.169	4.178	4.188	4.198	4.207
12.5	4.217	4.227	4.236	4.246	4.256
12.6	4.266	4.276	4.285	4.295	4.305
12.7	4.315	4.325	4.335	4.345	4.355
12.8	4.365	4.375	4.385	4.395	4.406
12.9	4.416	4.426	4.436	4.446	4.457
13.0	4.467	4.477	4.487	4.498	4.508
13.1	4.519	4.529	4.539	4.550	4.560
13.2	4.571	4.581	4.592	4.603	4.613
13.3	4.624	4.634	4.645	4.656	4.667
13.4	4.677	4.688	4.699	4.710	4.721
13.5	4.732	4.742	4.753	4.764	4.775
13.6	4.786	4.797	4.808	4.819	4.831
13.7	4.842	4.853	4.864	4.875	4.887
13.8	4.898	4.909	4.920	4.932	4.943
13.9	4.955	4.966	4.977	4.989	5.000

dB	0.00	0.02	0.04	0.06	0.08
14.0	5.012	5.023	5.035	5.047	5.058
14.1	5.070	5.082	5.093	5.105	5.117
14.2	5.129	5.140	5.152	5.164	5.176
14.3	5.188	5.200	5.212	5.224	5.236
14.4	5.248	5.260	5.272	5.284	5.297
14.5	5.309	5.321	5.333	5.346	5.358
14.6	5.370	5.383	5.395	5.408	5.420
14.7	5.433	5.445	5.458	5.470	5.483
14.8	5.495	5.508	5.521	5.534	5.546
14.9	5.559	5.572	5.585	5.598	5.610
15.0	5.623	5.636	5.649	5.662	5.675
15.1	5.689	5.702	5.715	5.728	5.741
15.2	5.754	5.768	5.781	5.794	5.808
15.3	5.821	5.834	5.848	5.861	5.875
15.4	5.888	5.902	5.916	5.929	5.943
15.5	5.957	5.970	5.984	5.998	6.012
15.6	6.026	6.039	6.053	6.067	6.081
15.7	6.095	6.109	6.124	6.138	6.152
15.8	6.166	6.180	6.194	6.209	6.223
15.9	6.237	6.252	6.266	6.281	6.295
16.0	6.310	6.324	6.339	6.353	6.368
16.1	6.383	6.397	6.412	6.427	6.442
16.2	6.457	6.471	6.486	6.501	6.516
16.3	6.531	6.546	6.561	6.577	6.592
16.4	6.607	6.622	6.637	6.653	6.668
16.5	6.683	6.699	6.714	6.730	6.745
16.6	6.761	6.776	6.792	6.808	6.823
16.7	6.839	6.855	6.871	6.887	6.902
16.8	6.918	6.934	6.950	6.966	6.982
16.9	6.998	7.015	7.031	7.047	7.063
17.0	7.079	7.096	7.112	7.129	7.145
17.0	7.161	7.178	7.194	7.211	7.228
17.2	7.244	7.261	7.278	7.295	7.311
17.3	7.328	7.345	7.362	7.379	7.396
17.4	7.413	7.430	7.447	7.464	7.482
17.5	7.499	7.516	7.534	7.551	7.568
17.6	7.586	7.603	7.621	7.638	7.656
17.7	7.674	7.691	7.709	7.727	7.745
17.8	7.762	7.780	7.798	7.816	7.834
17.9	7.852	7.870	7.889	7.907	7.925
18.0	7.943	7.962	7.980	7.998	8.017
18.1	8.035	8.054	8.072	8.091	8.110
18.2	8.128	8.147	8.166	8.185	8.204
18.3	8.222	8.241	8.260	8.279	8.299
18.4	8.318	8.337	8.356	8.375	8.395
18.5	8.414	8.433	8.453	8.472	8.492
18.6	8.511	8.531	8.551	8.570	8.590
18.7	8.610	8.630	8.650	8.670	8.690
18.8	8.710	8.730	8.750	8.770	8.790
18.9	8.810	8.831	8.851	8.872	8.892
19.0	8.913	8.933	8.954	8.974	8.995
19.1	9.016	9.036	9.057	9.078	8.099
19.2	9.120	9.141	9.162	9.183	9.204
19.3	9.226	9.247	9.268	9.290	9.311
19.4	9.333	9.354	9.376	9.397	9.419
19.5	9.441	9.462	9.484	9.506	9.528
19.6	9.550	9.572	9.594	9.616	9.638
19.7	9.661	9.683	9.705	9.727	9.750
19.8	9.772	9.795	9.817	9.840	9.863
19.9	9.886	9.908	9.931	9.954	9.977
20.0	10.000	10.023	10.047	10.072	10.096

TABLE V8

VOLTAGE ADDITION

TWO SIGNALS, OR CROSS-MOD. COMPONENTS, COMBINED ON A VOLTAGE BASIS.

GIVEN: dB DIFFERENCE BETWEEN THE TWO LEVELS;

FIND: dBs TO ADD TO HIGHER LEVEL TO GET TOTAL LEVEL IN dBs.

dB Difference	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.0	6.02	5.97	5.92	5.87	5.82	5.77	5.73	5.68	5.63	5.58
1.0	5.53	5.49	5.44	5.39	5.35	5.30	5.26	5.21	5.17	5.12
2.0	5.08	5.03	4.99	4.94	4.90	4.86	4.82	4.78	4.73	4.69
3.0	4.65	4.61	4.57	4.53	4.49	4.45	4.41	4.37	4.33	4.29
4.0	4.25	4.21	4.17	4.13	4.10	4.06	4.02	3.98	3.95	3.91
5.0	3.88	3.84	3.80	3.77	3.73	3.70	3.66	3.63	3.60	3.56
6.0	3.53	3.50	3.46	3.43	3.40	3.36	3.33	3.30	3.27	3.24
7.0	3.21	3.18	3.15	3.12	3.09	3.06	3.03	3.00	2.97	2.94
8.0	2.91	2.88	2.86	2.83	2.80	2.77	2.74	2.72	2.69	2.66
9.0	2.64	2.61	2.59	2.56	2.53	2.51	2.48	2.46	2.44	2.41
10.0	2.39	2.36	2.34	2.32	2.29	2.27	2.25	2.22	2.20	2.18
11.0	2.16	2.13	2.11	2.09	2.07	2.05	2.03	2.01	1.99	1.97
12.0	1.95	1.93	1.91	1.89	1.87	1.85	1.83	1.81	1.79	1.77
13.0	1.75	1.74	1.72	1.70	1.68	1.67	1.65	1.63	1.61	1.60
14.0	1.58	1.56	1.55	1.53	1.51	1.50	1.48	1.47	1.45	1.44
15.0	1.42	1.41	1.39	1.38	1.36	1.35	1.33	1.32	1.31	1.29
16.0	1.28	1.26	1.25	1.24	1.22	1.21	1.20	1.19	1.17	1.16
17.0	1.15	1.14	1.12	1.11	1.10	1.09	1.08	1.06	1.05	1.04
18.0	1.03	1.02	1.01	1.00	0.99	0.98	0.96	0.95	0.94	0.93
19.0	0.92	0.91	0.90	0.89	0.88	0.87	0.86	0.86	0.85	0.84
20.0	0.83	0.82	0.81	0.80	0.79	0.78	0.77	0.77	0.76	0.75
21.0	0.74	0.73	0.73	0.72	0.71	0.70	0.69	0.69	0.68	0.67
22.0	0.66	0.66	0.65	0.64	0.64	0.63	0.62	0.61	0.61	0.60
23.0	0.59	0.59	0.58	0.57	0.57	0.56	0.56	0.55	0.54	0.54
24.0	0.53	0.53	0.52	0.51	0.51	0.50	0.50	0.49	0.49	0.48
25.0	0.48	0.47	0.46	0.46	0.45	0.45	0.44	0.44	0.43	0.43
26.0	0.42	0.42	0.42	0.41	0.41	0.40	0.40	0.39	0.39	0.38
27.0	0.38	0.38	0.37	0.37	0.36	0.36	0.35	0.35	0.35	0.34
28.0	0.34	0.34	0.33	0.33	0.32	0.32	0.32	0.31	0.31	0.31
29.0	0.30	0.30	0.30	0.29	0.29	0.29	0.28	0.28	0.28	0.27
30.0	0.27	0.27	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.24
31.0	0.24	0.24	0.24	0.23	0.23	0.23	0.23	0.22	0.22	0.22
32.0	0.22	0.21	0.21	0.21	0.21	0.20	0.20	0.20	0.20	0.19
33.0	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.18	0.18	0.17
34.0	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.15
35.0	0.15	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.14	0.14
36.0	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.12
37.0	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11
38.0	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10
39.0	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
40.0	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08

TABLE V9 CONVERSION BETWEEN dBmV, RMS VOLTAGE, RMS CURRENT, AND POWER, at 75 OHMS

Abbreviations Used:

Voltage
μV.....microvolts .....10^{-6}volts
mV.....millivolts .....10^{-3} volts

Current
nA.....nanoamperes .....10^{-9} amp.
μA.....microamperes ....10^{-6} amp.
mA.....milliamperes .....10^{-3} amp.

Power
fW.....femtowatts .....10^{-15} watts
pW.....picowatts .....10^{-12} watts
nW.....nanowatts .....10^{-9} watts
μW.....microwatts .....10^{-6} watts
mW.....milliwatts .....10^{-3} watts

dBmV	RMS Voltage	RMS Current	Power
−60	1.00 μV	13.30 nA	13.30 fW
−59	1.12 μV	15.00 nA	16.80 fW
−58	1.26 μV	16.80 nA	21.10 fW
−57	1.41 μV	18.80 nA	26.60 fW
−56	1.59 μV	21.10 nA	33.50 fW
−55	1.78 μV	23.70 nA	42.20 fW
−54	2.00 μV	26.60 nA	53.10 fW
−53	2.24 μV	29.90 nA	66.80 fW
−52	2.51 μV	33.50 nA	84.10 fW
−51	2.82 μV	37.60 nA	106.00 fW
−50	3.16 μV	42.20 nA	133.00 fW
−49	3.55 μV	47.30 nA	168.00 fW
−48	3.98 μV	53.10 nA	211.00 fW
−47	4.47 μV	59.60 nA	266.00 fW
−46	5.02 μV	66.80 nA	335.00 fW
−45	5.62 μV	75.00 nA	422.00 fW
−44	6.31 μV	84.10 nA	531.00 fW
−43	7.08 μV	94.40 nA	668.00 fW
−42	7.94 μV	106.00 nA	841.00 fW
−41	8.91 μV	119.00 nA	1.06 pW
−40	10.00 μV	133.00 nA	1.33 pW
−39	11.20 μV	150.00 nA	1.68 pW
−38	12.60 μV	168.00 nA	2.11 pW
−37	14.10 μV	188.00 nA	2.66 pW
−36	15.90 μV	211.00 nA	3.35 pW
−35	17.80 μV	237.00 nA	4.22 pW
−34	20.00 μV	266.00 nA	5.31 pW
−33	22.40 μV	299.00 nA	6.68 pW
−32	25.10 μV	335.00 nA	8.41 pW
−31	28.20 μV	376.00 nA	10.60 pW
−30	31.60 μV	422.00 nA	13.30 pW
−29	35.50 μV	473.00 nA	16.80 pW
−28	39.80 μV	531.00 nA	21.10 pW
−27	44.70 μV	596.00 nA	26.60 pW
−26	50.10 μV	668.00 nA	33.50 pW
−25	56.20 μV	750.00 nA	42.20 pW
−24	63.10 μV	841.00 nA	53.10 pW
−23	70.80 μV	944.00 nA	66.80 pW
−22	79.40 μV	1.06 μA	84.10 pW
−21	89.10 μV	1.19 μA	106.00 pW
−20	100.00 μV	1.33 μA	133.00 pW
−19	112.00 μV	1.50 μA	168.00 pW
−18	126.00 μV	1.68 μA	211.00 pW
−17	141.00 μV	1.88 μA	266.00 pW
−16	159.00 μV	2.11 μA	335.00 pW
−15	178.00 μV	2.37 μA	422.00 pW
−14	200.00 μV	2.66 μA	531.00 pW
−13	224.00 μV	2.99 μA	668.00 pW
−12	251.00 μV	3.35 μA	841.00 pW
−11	282.00 μV	3.76 μA	1.06 nW
−10	316.00 μV	4.22 μA	1.33 nW
− 9	355.00 μV	4.73 μA	1.68 nW
− 8	398.00 μV	5.31 μA	2.11 nW
− 7	447.00 μV	5.96 μA	2.66 nW
− 6	501.00 μV	6.68 μA	3.35 nW
− 5	562.00 μV	7.50 μA	4.22 nW
− 4	631.00 μV	8.41 μA	5.31 nW
− 3	708.00 μV	9.44 μA	6.68 nW
− 2	794.00 μV	10.60 μA	8.41 nW
− 1	881.00 μV	11.90 μA	10.60 nW

dBmV	RMS Voltage	RMS Current	Power
0	1000.00 μV	13.30 μA	13.30 nW
+ 1	1.12 mV	15.00 μA	16.80 nW
+ 2	1.26 mV	16.80 μA	21.10 nW
+ 3	1.41 mV	18.80 μA	26.60 nW
+ 4	1.59 mV	21.10 μA	33.50 nW
+ 5	1.78 mV	23.70 μA	42.20 nW
+ 6	2.00 mV	26.60 μA	53.10 nW
+ 7	2.24 mV	29.90 μA	66.80 nW
+ 8	2.51 mV	33.50 μA	84.10 nW
+ 9	2.82 mV	37.60 μA	106.00 nW
+10	3.16 mV	42.20 μA	133.00 nW
+11	3.55 mV	47.30 μA	168.00 nW
+12	3.98 mV	53.10 μA	211.00 nW
+13	4.47 mV	59.60 μA	266.00 nW
+14	5.01 mV	66.80 μA	335.00 nW
+15	5.62 mV	75.00 μA	422.00 nW
+16	6.31 mV	84.10 μA	531.00 nW
+17	7.08 mV	94.40 μA	668.00 nW
+18	7.98 mV	106.00 μA	841.00 nW
+19	8.91 mV	119.00 μA	1.06 μW
+20	10.00 mV	133.00 μA	1.33 μW
+21	11.20 mV	150.00 μA	1.68 μW
+22	12.60 mV	168.00 μA	2.11 μW
+23	14.10 mV	188.00 μA	2.66 μW
+24	15.90 mV	211.00 μA	3.35 μW
+25	17.80 mV	237.00 μA	4.22 μW
+26	20.00 mV	266.00 μA	5.31 μW
+27	22.40 mV	299.00 μA	6.68 μW
+28	25.10 mV	335.00 μA	8.41 μW
+29	28.20 mV	376.00 μA	10.60 μW
+30	31.60 mV	422.00 μA	13.30 μW
+31	35.50 mV	473.00 μA	16.80 μW
+32	39.80 mV	531.00 μA	21.10 μW
+33	44.70 mV	596.00 μA	26.60 μW
+34	50.10 mV	668.00 μA	33.50 μW
+35	56.20 mV	750.00 μA	42.20 μW
+36	63.10 mV	841.00 μA	53.10 μW
+37	70.80 mV	944.00 μA	66.80 μW
+38	79.40 mV	1.06 mA	84.10 μW
+39	89.10 mV	1.19 mA	106.00 μW
+40	100.00 mV	1.33 mA	133.00 μW
+41	112.00 mV	1.50 mA	168.00 μW
+42	126.00 mV	1.68 mA	211.00 μW
+43	141.00 mV	1.88 mA	266.00 μW
+44	159.00 mV	2.11 mA	335.00 μW
+45	178.00 mV	2.37 mA	422.00 μW
+46	200.00 mV	2.66 mA	531.00 μW
+47	224.00 mV	2.99 mA	668.00 μW
+48	251.00 mV	3.35 mA	841.00 μW
+49	282.00 mV	3.76 mA	1.06 mW
+50	316.00 mV	4.22 mA	1.33 mW
+51	355.00 mV	4.73 mA	1.68 mW
+52	398.00 mV	5.31 mA	2.11 mW
+53	447.00 mV	5.96 mA	2.66 mW
+54	501.00 mV	6.68 mA	3.35 mW
+55	562.00 mV	7.50 mA	4.22 mW
+56	631.00 mV	8.41 mA	5.31 mW
+57	708.00 mV	9.44 mA	6.68 mW
+58	794.00 mV	10.60 mA	8.41 mW
+59	891.00 mV	11.90 mA	10.60 mW
+60	1000.00 mV	13.30 mA	13.30 mW

TABLE T1 RETURN LOSS, REFLECTION COEFFICIENT, AND VSWR

EXAMPLE: Assume that a discontinuity exists in a transmission line, producing a reflected wave whose amplitude is "ρ" times that of the main wave: $E_r = \rho E_m$;
where E_r is the rms voltage of the reflected wave
and E_m is the rms voltage of the main wave.

The reflection coefficient expressed in percent = 100 ρ, and expressed as a return loss in dB = 20 $\log_{10} \rho$.

At points along the line where the reflected wave and the main wave are in phase, they add to produce a voltage maximum: $E_{max} = E_m + E_r = E_m (1 + \rho)$.

At points where they are 180° out of phase, they subtract to produce a voltage minimum: $E_{min} = E_m - E_r = E_m (1 - \rho)$.

Then the VSWR "S" (ratio of maximum to minimum voltage) is: $S = \frac{E_{max}}{E_{min}} = \frac{E_m + E_r}{E_m - E_r} = \frac{E_m (1+\rho)}{E_m (1-\rho)} = \frac{1+\rho}{1-\rho}$,

and in terms of S, $\rho = \frac{S-1}{S+1}$.

Return Loss dB down	Reflection Coefficient %	VSWR	Return Loss dB down	Reflection Coefficient %	VSWR	Return Loss dB down	Reflection Coefficient %	VSWR
0.0	100.00	∞						
0.5	94.4	34.7	20.5	9.44	1.208	40.5	.944	1.0191
1.0	89.1	17.3	21.0	8.91	1.196	41.0	.891	1.0180
1.5	84.1	11.6	21.5	8.41	1.184	41.5	.841	1.0170
2.0	79.4	8.71	22.0	7.94	1.172	42.0	.794	1.0160
2.5	75.0	7.00	22.5	7.50	1.162	42.5	.750	1.0151
3.0	70.8	5.85	23.0	7.08	1.152	43.0	.708	1.0143
3.5	66.8	5.02	23.5	6.68	1.143	43.5	.668	1.0134
4.0	63.1	4.42	24.0	6.31	1.135	44.0	.631	1.0127
4.5	59.6	3.95	24.5	5.96	1.127	44.5	.596	1.0120
5.0	56.2	3.57	25.0	5.62	1.119	45.0	.562	1.0113
5.5	53.1	3.26	25.5	5.31	1.112	45.5	.531	1.0107
6.0	50.1	3.01	26.0	5.01	1.105	46.0	.501	1.0101
6.5	47.3	2.80	26.5	4.73	1.099	46.5	.473	1.0095
7.0	44.7	2.62	27.0	4.47	1.094	47.0	.447	1.0090
7.5	42.2	2.46	27.5	4.22	1.088	47.5	.422	1.0085
8.0	39.8	2.32	28.0	3.98	1.083	48.0	.398	1.0080
8.5	37.6	2.21	28.5	3.76	1.078	48.5	.376	1.0075
9.0	35.5	2.10	29.0	3.55	1.074	49.0	.355	1.0071
9.5	33.5	2.01	29.5	3.35	1.069	49.5	.335	1.0067
10.0	31.6	1.92	30.0	3.16	1.065	50.0	.316	1.0063
10.5	29.9	1.85	30.5	2.99	1.062	50.5	.299	1.0060
11.0	28.2	1.79	31.0	2.82	1.058	51.0	.282	1.0057
11.5	26.6	1.72	31.5	2.66	1.055	51.5	.266	1.0053
12.0	25.1	1.67	32.0	2.51	1.051	52.0	.251	1.0050
12.5	23.7	1.62	32.5	2.37	1.049	52.5	.237	1.0048
13.0	22.4	1.58	33.0	2.24	1.046	53.0	.224	1.0045
13.5	21.1	1.53	33.5	2.11	1.043	53.5	.211	1.0042
14.0	20.0	1.50	34.0	2.00	1.041	54.0	.200	1.0040
14.5	18.8	1.46	34.5	1.88	1.038	54.5	.188	1.0038
15.0	17.8	1.43	35.0	1.78	1.036	55.0	.178	1.0035
15.5	16.8	1.40	35.5	1.68	1.034	55.5	.168	1.0034
16.0	15.9	1.38	36.0	1.59	1.032	56.0	.159	1.0032
16.5	15.0	1.35	36.5	1.50	1.030	56.5	.150	1.0030
17.0	14.1	1.33	37.0	1.41	1.029	57.0	.141	1.0028
17.5	13.3	1.31	37.5	1.33	1.027	57.5	.133	1.0027
18.0	12.6	1.29	38.0	1.26	1.026	58.0	.126	1.0025
18.5	11.9	1.27	38.5	1.19	1.024	58.5	.119	1.0024
19.0	11.2	1.25	39.0	1.12	1.023	59.0	.112	1.0022
19.5	10.6	1.233	39.5	1.06	1.021	59.5	.106	1.0021
20.0	10.0	1.222	40.0	1.00	1.020	60.0	.100	1.0020

TABLE T2. CHANNEL VARIABLES–INTRODUCTION

½ WAVELENGTH IN AIR: The velocity of radio waves in air is the same as the velocity of light: 300,000,000 (3×10^8) meters per second. Since one meter equals 39.37 inches, the velocity of radio waves, expressed in inches per second, is $39.37 \times 3 \times 10^8 = 1.181 \times 10^{10}$ inches per second.

One wavelength is the distance a wave travels while one cycle is completed. If the cycle is completed in one second, the wave has a frequency of one Hertz (1 Hz). Hence the wavelength "λ" for 1 Hz equals the distance the wave travels in one second, which is 1.181×10^{10} inches, and for a freqency of f_{Hz}:

$$\lambda = \frac{1.181 \times 10^{10}}{f_{Hz}} \text{ inches.}$$

In CATV, frequency is more conveniently expressed in mega-Hertz (MHz), 1 MHz being 10^6 Hz.

Thus $\lambda = \frac{1.181 \times 10^{10}}{f_{Hz} \times 10^6} = \frac{11{,}810}{f_{MHz}}$ inches, and the half wavelength $\frac{\lambda}{2} = \frac{5905}{f_{MHz}}$ inches.

½ wavelength in other dielectrics: A dielectric other than air has the effect of slowing the wave down, so one wavelength becomes shorter:

$$\text{Wavelength in dielectric} = \text{wavelength in air} \times \frac{1}{\sqrt{\varepsilon}}$$

where ε is the dielectric constant of the material.

For solid polyethylene, $\varepsilon = 2.26$ so $\frac{1}{\sqrt{\varepsilon}} = 0.665$

and ½ wavelength $= \frac{0.665 \times 5900^*}{f_{MHz}} = \frac{3920}{f_{MHz}}$ inches;

for the usual foamed polyethylene $\varepsilon = 1.51$ so $\frac{1}{\sqrt{\varepsilon}} = 0.81$

and ½ wavelength $= \frac{0.81 \times 5900}{f_{MHz}} = \frac{4779}{f_{MHz}}$ inches.

THE DIPOLE ANTENNA FACTOR is convenient when a field strength meter, calibrated in dBmV, is used with a dipole antenna to measure field strength. The factor is the number of dB which must be added to the output (in dBmV) of a ½ wavelength dipole to obtain the field strength in dBu (dB above one microvolt per meter).

The factor is listed on Table T2 for each TV channel. It is derived as follows:

When a 75-ohm half-wave dipole antenna is exposed to an r-f field, the rms voltage delivered to a 75-ohm load is:

$$V = \frac{5.58 \times \sqrt{75}}{1000} \times \frac{E}{f_{MHz}} = 0.0483 \frac{E}{f_{MHz}} \text{ mV}_{rms}$$

or, if the voltage is known:

$$E = 20.7\ V \times f_{MHz} \text{ microvolts per meter}$$

where:

V is the output voltage in millivolts rms

E is the field strength in microvolts per meter

f_{MHz} is the signal frequency in MHz

For greatest convenience in CATV work, output level should be expressed in dBmV (dB above one millivolt) and the field strength level in dBu (dB above one microvolt per meter).

In the above expression the field strength level in dBu is $20 \log_{10} E$

so: field strength level (dBu) $= 20 \log_{10} E$
$= 20 \log_{10} V + 20 \log_{10} (20.7 \times f_{MHz})$

$20 \log_{10} V$ is the level in dBmV, so if we let
$20 \log_{10} (20.7 \times f_{MHz})$ = dipole antenna factor, then

field strength level (dBu) =
dipole output (dBmV) + dipole antenna factor.

Examples:

1. A field strength meter using a half-wave dipole on channel 12 indicates an antenna output level of −18 dBmV.

   From table T2: for channel 12, dipole antenna factor = 72.54 db. So field strength level is 72.54–18 = 54.54 dBu.

2. The field strength level at a given location on channel 6 is predicted to be +12 dBu at an elevation of 30 feet. What is the expected output level from an antenna array having a gain of 15 dB, mounted at an elevation of 300 feet?

Three factors are involved in determining the output level:

a. The height is increased 10X, from 30 to 300 feet. Assuming linear increase of field strength with height, this is handled by adding **20** dB.

b. The antenna gain adds **15** dB.

c. Since field strength level = dipole output + dipole antenna factor from the table: factor = 64.72 for channel 6;

   so: 64.72 dB is subtracted.

The expected output level in dBmV is thus:

$$+12 + 20 + 15 - 64.72 = \mathbf{-17.72\ dBmV}$$

* Rounded off.

TABLE T2 TV CHANNEL FREQUENCIES AND CORRESPONDING DI-POLES

Channel No.	Picture Carrier MHz	Sound Carrier MHz	½ Wave Length, Inches — Type of Dielectric			Di-Pole Antenna Factor dB	Channel No.	Picture Carrier MHz	Sound Carrier MHz	½ Wave Length, Inches — Type of Dielectric			Di-Pole Antenna Factor dB
			Air	Foam	Solid					Air	Foam	Solid	
2	55.25	59.75	103.8	84.0	68.5	61.2	43	645.25	649.75	9.2	7.4	6.1	82.5
3	61.25	65.75	93.8	76.0	61.9	62.1	44	651.25	655.75	9.1	7.4	6.0	82.6
4	67.25	71.75	85.7	69.4	56.6	62.9	45	657.25	661.75	9.0	7.3	5.9	82.6
5	77.25	81.75	74.8	60.6	49.4	64.1	46	663.25	667.75	8.9	7.2	5.9	82.7
6	83.25	87.75	69.5	56.3	45.9	64.7	47	669.25	673.75	8.8	7.2	5.8	82.7
7	175.25	179.75	33.4	27.0	22.0	71.2	48	675.25	679.75	8.7	7.1	5.7	82.8
8	181.25	185.75	32.8	25.6	21.6	71.5	49	681.25	685.75	8.7	7.1	5.7	82.9
9	187.25	191.75	31.5	25.5	19.8	71.8	50	687.25	691.75	8.6	7.0	5.6	83.0
10	193.25	197.75	30.0	24.5	20.0	72.0	51	693.25	697.75	8.5	6.9	5.6	83.1
11	199.25	203.75	29.4	23.8	19.4	72.3	52	699.25	703.75	8.4	6.8	5.5	83.1
12	205.25	209.75	28.5	23.0	18.8	72.5	53	705.25	709.75	8.4	6.8	5.5	83.2
13	211.25	215.75	27.7	22.5	18.2	72.8	54	711.25	715.75	8.3	6.7	5.5	83.3
14	471.25	475.75	12.5	10.1	8.2	79.8	55	717.25	721.75	8.2	6.6	5.4	83.3
15	477.25	481.75	12.4	10.0	8.1	79.9	56	723.25	727.75	8.1	6.5	5.3	83.4
16	483.25	487.75	12.2	9.9	8.0	80.0	57	729.25	733.75	8.0	6.5	5.3	83.5
17	489.25	493.75	12.0	9.7	7.9	80.1	58	735.25	739.75	8.0	6.5	5.3	83.6
18	495.25	499.75	11.9	9.6	7.8	80.2	59	741.25	745.75	7.9	6.4	5.2	83.6
19	501.25	505.75	11.8	9.5	7.7	80.3	60	747.25	751.75	7.8	6.3	5.2	83.7
20	507.25	511.75	11.6	9.4	7.6	80.4	61	753.25	757.75	7.8	6.3	5.2	83.8
21	513.25	517.75	11.5	9.3	7.5	80.5	62	759.25	763.75	7.7	6.2	5.1	83.9
22	519.25	523.75	11.3	9.2	7.4	80.6	63	765.25	769.75	7.7	6.2	5.1	84.0
23	525.25	529.75	11.2	9.1	7.4	80.7	64	771.25	775.75	7.6	6.2	5.0	84.1
24	531.25	535.75	11.1	9.0	7.3	80.8	65	777.25	781.75	7.5	6.1	4.9	84.1
25	537.25	541.75	11.0	8.9	7.2	80.9	66	783.25	787.75	7.5	6.1	4.9	84.2
26	543.25	547.75	10.8	8.7	7.1	81.0	67	789.25	793.75	7.4	6.0	4.9	84.3
27	549.25	553.75	10.7	8.7	7.1	81.1	68	795.25	799.75	7.4	6.0	4.9	84.4
28	555.25	559.75	10.6	8.6	7.0	81.2	69	801.25	805.75	7.3	5.9	4.8	84.4
29	561.25	565.75	10.5	8.5	6.9	81.3	70	807.25	811.75	7.3	5.9	4.8	84.5
30	567.25	571.75	10.4	8.4	6.9	81.4	71	813.25	817.75	7.2	5.8	4.7	84.5
31	573.25	577.75	10.3	8.3	6.8	81.5	72	819.25	823.75	7.2	5.8	4.7	84.6
32	579.25	583.75	10.2	8.3	6.7	81.6	73	825.25	829.75	7.1	5.7	4.6	84.6
33	585.25	589.75	10.1	8.2	6.6	81.7	74	831.25	835.75	7.0	5.7	4.6	84.7
34	591.25	595.75	10.0	8.1	6.6	81.8	75	837.25	841.75	7.0	5.7	4.6	84.8
35	597.25	601.75	9.9	8.0	6.5	81.9	76	843.25	847.75	6.9	5.6	4.6	84.8
36	603.25	607.75	9.8	7.9	6.4	82.0	77	849.25	853.75	6.9	5.6	4.6	84.9
37	609.25	613.75	9.7	7.8	6.3	82.1	78	855.25	859.75	6.8	5.5	4.5	84.9
38	615.25	519.75	9.6	7.7	6.3	82.2	79	861.25	865.75	6.8	5.5	4.5	85.0
39	621.25	625.75	9.5	7.7	6.2	82.3	80	867.25	871.75	6.8	5.5	4.5	85.0
40	627.25	631.75	9.4	7.6	6.2	82.3	81	873.25	877.75	6.7	5.4	4.4	85.1
41	633.25	637.75	9.3	7.5	6.1	82.4	82	879.25	883.75	6.7	5.4	4.4	85.2
42	639.25	643.75	9.2	7.4	6.1	82.4	83	885.25	889.75	6.6	5.3	4.4	85.3

NOTE: Propagation velocity in cable with polyfoam dielectric is calculated at 81% of that in free space; solid polyethylene at 66%.

CABLE ATTENUATION

To convert nominal cable attenuation given in dB/100 ft. at 70°F into dB/100 meters at 21°C: Multiply by 3.281.

Appendix I

THE DETAILED MATHEMATICAL DEVELOPMENT OF THE DISTORTION COMPONENTS

Let $e_{in} = A\cos a + B\cos b + C\cos c$

where $a > b > c$

and $e_{out} = k_1 e_{in} + k_2 e_{in}^2 + k_3 e_{in}^3$

First Order Components:

By direct multiplication:

$$k_1 e_{in} = k_1 A\cos a + k_1 B\cos b + k_1 C\cos c$$

Second Order Components:

$$k_2 e_{in}^2 =$$
$$= k_2 (A\cos a + B\cos b + C\cos c)^2$$
$$= k_2 A^2\cos^2 a + k_2 B^2\cos^2 b + k_2 C^2\cos^2 c$$
$$+ 2k_2 AB\cos a\cos b + 2k_2 AC\cos a\cos c + 2k_2 BC\cos b\cos c$$

To reduce these expressions to ones containing identifiable frequencies, expand each term in accordance with the applicable one of the following two relationships (eq. 1 or 2): (These can be found in any elementary trigonometry text, or on pages 1041-2 of the ITT "Reference Data for Radio Engineers" Fourth Edition.)

equation 1 $$\cos x \cos y = \frac{1}{2}\cos(x+y) + \frac{1}{2}\cos(x-y)$$

equation 2 $$\cos^2 x = \frac{1}{2} + \frac{1}{2}\cos 2x$$

Substituting the appropriate expressions from above into eq. (2) gives the DC and second harmonic components:

$$k_2 A^2\cos^2 a = \frac{k_2 A^2}{2} + \frac{k_2 A^2}{2}\cos 2a$$

$$k_2 B^2\cos^2 b = \frac{k_2 B^2}{2} + \frac{k_2 B^2}{2}\cos 2b$$

$$k_2 C^2\cos^2 c = \frac{k_2 C^2}{2} + \frac{k_2 C^2}{2}\cos 2c$$

Substituting the other three expressions from above into eq. (1) gives the sum and difference beat components:

$$2k_2 AB\cos a\cos b = k_2 AB\cos(a+b) + k_2 AB\cos(a-b)$$
$$2k_2 AC\cos a\cos c = k_2 AC\cos(a+c) + k_2 AC\cos(a-c)$$
$$2k_2 BC\cos b\cos c = k_2 BC\cos(b+c) + k_2 BC\cos(b-c)$$

Third Order Components:

$$k_3 e_{in}^3 = k_3(A\cos a + B\cos b + C\cos c)^3$$
$$= k_3 A^3\cos^3 a + k_3 B^3\cos^3 b + k_3 C^3\cos^3 c$$
$$+ 3k_3 A^2 B\cos^2 a\cos b + 3k_3 A^2 C\cos^2 a\cos c$$
$$+ 3k_3 B^2 C\cos^2 b\cos c + 3k_3 B^2 A\cos^2 b\cos a$$
$$+ 3k_3 C^2 A\cos^2 c\cos a + 3k_3 C^2 B\cos^2 c\cos b$$
$$+ 6k_3 ABC\cos a\cos b\cos c$$

Three trigonometric relationships are needed to allow expansion of the terms of the types "$\cos^3 x$", "$\cos^2 x\cos y$", and "$\cos x\cos y\cos z$".

From the ITT handbook (loc. cit.) p. 1041:

$$\cos 3x = -3\cos x + 4\cos^3 x$$

$$4\cos^3 x = 3\cos x + \cos 3x$$

giving eq. 3 $\boxed{\cos^3 x = \frac{3}{4}\cos x + \frac{1}{4}\cos 3x}$

$$\cos^2 x \cos y = (\frac{1}{2} + \frac{1}{2}\cos 2x)\cos y \text{ (substituting from eq. 2)}$$

$$= \frac{1}{2}\cos y + \frac{1}{2}\cos 2x \cos y$$

but: $\cos 2x \cos y = \frac{1}{2}\cos(2x + y) + \frac{1}{2}\cos(2x - y)$

giving eq. 4

$$\boxed{\cos^2 x \cos y = \frac{1}{2}\cos y + \frac{1}{4}\cos(2x + y) + \frac{1}{4}\cos(2x - y)}$$

$$\cos x \cos y \cos z = (\cos x \cos y)\cos z$$

$$= \left[\frac{1}{2}\cos(x + y) + \frac{1}{2}\cos(x - y)\right]\cos z$$

$$= \frac{1}{2}\cos(x + y)\cos z + \frac{1}{2}\cos(x - y)\cos z$$

$$= \frac{1}{2}\left[\frac{1}{2}\cos(x + y + z) + \frac{1}{2}\cos(x + y - z)\right]$$

$$+ \frac{1}{2}\left[\frac{1}{2}\cos(x - y + z) + \frac{1}{2}\cos(x - y - z)\right]$$

giving eq. 5

$$\boxed{\cos x \cos y \cos z = \frac{1}{4}\cos(x + y + z) + \frac{1}{4}\cos(x + y - z) + \frac{1}{4}\cos(x - y + z) + \frac{1}{4}(x - y - z)}$$

Applying eq. 3 to the appropriate terms gives the self-expansion/compression and third harmonic components:

$$k_3A^3\cos^3 a = \frac{3}{4}k_3A^3\cos a + \frac{1}{4}k_3A^3\cos 3a$$

$$k_3B^3\cos^3 b = \frac{3}{4}k_3B^3\cos b + \frac{1}{4}k_3B^3\cos 3b$$

$$k_3C^3\cos^3 c = \frac{3}{4}k_3C^3\cos c + \frac{1}{4}k_3C^3\cos 3c$$

Applying eq. 3 to the appropriate terms gives the cross-expansion/compression and intermodulation components:

$$3k_3A^2B\cos^2 a\cos b = \frac{3}{2}k_3A^2B\cos b + \frac{3}{4}k_3A^2B\cos(2a + b) + \frac{3}{4}k_3A^2B\cos(2a - b)$$

$$3k_3A^2C\cos^2 a\cos c = \frac{3}{2}k_3A^2C\cos c + \frac{3}{4}k_3A^2C\cos(2a + c) + \frac{3}{4}k_3A^2C\cos(2a - c)$$

$$3k_3B^2C\cos^2 b\cos c = \frac{3}{2}k_3B^2C\cos c + \frac{3}{4}k_3B^2C\cos(2b + c) + \frac{3}{4}k_3B^2C\cos(2b - c)$$

$$3k_3B^2A\cos^2 b\cos a = \frac{3}{2}k_3B^2A\cos a + \frac{3}{4}k_3B^2A\cos(2b + a) + \frac{3}{4}k_3B^2A\cos(2b - a)$$

$$3k_3C^2A\cos^2 c\cos a = \frac{3}{2}k_3C^2A\cos a + \frac{3}{4}k_3C^2A\cos(2c + a) + \frac{3}{4}k_3C^2A\cos(2c - a)$$

$$3k_3C^2B\cos^2 c\cos b = \frac{3}{2}k_3C^2B\cos b + \frac{3}{4}k_3C^2B\cos(2c + b) + \frac{3}{4}k_3C^2B\cos(2c - b)$$

Using eq. 5 gives the triple beat components:

$$6k_3ABC\cos a\cos b\cos c = \frac{3}{2}k_3ABC\cos(a + b + c) + \frac{3}{2}k_3ABC\cos(a + b - c)$$

$$+ \frac{3}{2}k_3ABC\cos(a - b + c) + \frac{3}{2}k_3ABC\cos(a - b - c)$$

Appendix II

THE DETAILED MATHEMATICAL DEVELOPMENT OF SELF- AND CROSS-COMPRESSION (AND EXPANSION) WITH UNMODULATED INPUT SIGNALS

The output voltage at f_a, for example, including the effects of distortion is:

$$e_{a(D)} = k_1A + 3/4\, k_3A^3 + 3/2\, k_3AB^2 + 3/2\, k_3AC^2$$

A measure of the degree of Cross-compression (or -expansion) is found by dividing this output by that which would occur if there were no distortion:

$$\frac{e_{a(D)}}{k_1A} = \frac{k_1A + 3/4\, k_3A^3 + 3/2\, k_3AB^2 + 3/2\, k_3AC^2}{k_1A}$$

$$= 1 + 3/4\,\frac{k_3}{k_1}\,A^2 + 3/2\,\frac{k_3}{k_1}\,B^2 + 3/2\,\frac{k_3}{k_1}\,C^2$$

Although the foregoing has only been concerned with conditions involving *three* CW input signals, in this case it is instructive to discover the relationship with any number of input signals. Assume all input amplitudes = A. Then:

$$\frac{e_{a(D)}}{k_1A} = 1 + 3/4\,\frac{k_3}{k_1}\,A^2 + 3/2\,\frac{k_3}{k_1}\,A^2 + 3/2\,\frac{k_3}{k_1}\,A^2 + +\ \text{etc.}$$

$$= 1 + \frac{k_3}{k_1}\,A^2\,(3/4 + 3/2 + 3/2 + \ldots.\ \text{etc.})$$

$$= 1 + 3/2\,\frac{k_3}{k_1}\,A^2\,(1/2 + 1 + 1 + \ldots.\ \text{etc.})$$

When there is one input signal the quantity in parentheses = ½, with two it = 1½, with three it = 2½ and in general:

equation "A"

$$\frac{e_{a(D)}}{k_1A} = 1 + 3/2\,\frac{k_3}{k_1}\,A^2\left(n - \frac{1}{2}\right)$$

where n is the total number of input signals.

To allow comparison between the various effects of third order distortion, a common measure of this distortion is needed. The triple beat component is chosen. Its amplitude is given by:

$$e_{abc} = 3/2\, k_3\, ABC;$$

where $A = B = C$, $e_{abc} = 3/2\, k_3A^3$.

and the ratio of this component to the first order output is:

$$\frac{e_{abc}}{k_1A} = \frac{3/2\, k_3A^3}{k_1A} = 3/2\,\frac{k_3}{k_1}\,A^2$$

Because this expression is frequently used in what follows, it is abbreviated r_{abc} (the ratio of the triple beat output voltage to the first order output voltage).

$$r_{abc} = \frac{e_{abc}}{k_1A} = 3/2\,\frac{k_3}{k_1}\,A^2.$$

(Note that r_{abc} may be either positive or negative depending on the sign of k_3.)

This is identical with the term preceding the parentheses in equation A. Substituting in that equation:

equation "B"

$$\frac{e_{a(D)}}{k_1A} = 1 + r_{abc}\left(n - \frac{1}{2}\right)$$

Which shows the relationship between the degree of expansion (or compression) and the ratio of Triple beat to first order output.

Compression or expansion, in dB is expressed

equation "C"

$$20 \log_{10} \frac{e_{a(D)}}{k_1A} = 20 \log_{10}\left[1 + r_{abc}\left(n - \frac{1}{2}\right)\right]$$

The tables for Compression and Expansion were computed by selecting progressive values for $R_{abc/a}$ $(= L_{abc} - L_a)$ and calculating the corresponding value for r_{abc} from the relationship: $R_{abc/a} = 20 \log_{10} r_{abc}$.

The value for r_{abc} was then inserted in equation B, with a − sign for compression, or a + sign for expansion. With a chosen number of inputs (n) the ratio of $\frac{e_{a(D)}}{k_1A}$ was then calculated. Finally this ratio was expressed in decibel form by the use of equation C.

Appendix III

THE DETAILED MATHEMATICAL DEVELOPMENT OF THE RELATIONSHIP BETWEEN CROSS-MODULATION AND THE TRIPLE BEAT RATIO

1. NCTA Standard Cross-Modulation

The NCTA Standard "Amplifier Distortion Characteristics" requires that the interfering signals be modulated approximately 100% with a 15.75 KHz square-wave [Section IV(D)], and that modulation on the desired carrier shall be expressed in terms of the "cross-modulation ratio," the ratio of the peak-to-peak variation in the amplitude of the desired carrier with interfering signals applied, to its amplitude with no interfering signals [Section IV(E)].

For the purposes of this analysis the effect of 100% square-wave modulation is achieved by assuming that the amplitudes of the interfering signals vary periodically between two extreme conditions. During the "ON" half of the modulation cycle the amplitudes of the interfering signals are given by: $B_{max} = B$, $C_{max} = C$, etc. During the "OFF" half of the modulation cycle, these amplitudes are given by:

$B_{min} = O$, $C_{min} = O$, etc.

When third-order distortion exists, the output voltage at f_a during the "ON" half of the modulation cycle is found by summing all the components at that frequency including the first order output (k_1A), the self-compression/expansion component ($3/4\ k_3A^3$) and the cross-compression/expansion components ($3/2\ k_3AB^2$, $3/2\ k_3AC^2$, and so on for any number of interfering signals). So:

$$e_{ON} = k_1A + 3/4\ k_3A^3 + 3/2\ k_3AB^2 + 3/2\ k_3AC^2 + +$$

etc. (including the effects of compression and cross-compression) and during the "OFF" half of the modulation cycle the amplitudes of the interfering signals are zero so the output at f_a is:

$$e_{OFF} = k_1A + 3/4\ k_3A^3$$

(including the effect of compression only).

The NCTA "cross-modulation ratio" (xm) is defined as the ratio of the variation on the output at f_a, to its amplitude with no other inputs:

$$xm = \frac{e_{ON} - e_{OFF}}{k_1A + 3/4\ k_3A^3}$$

$$= \frac{(k_1A + 3/4\ k_3A^3 + 3/2\ k_3AB^2 + 3/2\ k_3AC^2 + + \text{etc.}) - (k_1A + 3/4\ k_3A^3)}{k_1A + 3/4\ k_3A^3}$$

$$= \frac{3/2\ k_3AB^2 + 3/2\ k_3AC^2 \ldots + \ldots \text{etc.}}{k_1A + 3/4\ k_3A^3}$$

This can be simplified by assuming equal input amplitudes at all frequencies: ($A = B = C = $ etc.)

then $xm = \dfrac{(n-1)\ 3/2\ k_3A^3}{k_1A + 3/4\ k_3A^3}$ where n is the total number of input signals including the one at f_a.

To get this into a more convenient form, divide the numerator and the denominator by k_1A:

$$xm = \frac{(n-1)\ 3/2\ \dfrac{k_3}{k_1}A^2}{1 + \dfrac{1}{2}\left(3/2\ \dfrac{k_3}{k_1}A^2\right)}$$

In Appendix II the Triple Beat Ratio was defined as a convenient measure of third-order distortion:

$$r_{abc} = 3/2\frac{k_3}{k_1}A^2$$

Substituting this in the above equation:

$$xm = \frac{(n-1)\ r_{abc}}{1 + \dfrac{r_{abc}}{2}}$$

which expresses the NCTA Cross-Modulation Ratio in terms of the Triple Beat Ratio.

$\dfrac{r_{abc}}{2}$ is usually $< < 1$, so $1 + \dfrac{r_{abc}}{2} \approx 1$

and $xm \approx (n-1)\ r_{abc}$

This is accurate within 5% when:

$$1 + \frac{r_{abc}}{2} \leqq 1.05, \text{ or } \frac{r_{abc}}{2} \leqq 0.05 \text{ when } r_{abc} \leqq 0.1$$

A decibel expression for this relationship can be obtained by defining the NCTA decibel ratio:

$$XM = 20 \log_{10} xm$$

and the relative Triple Beat (in dB):

$$R_{abc/a} = 20 \log_{10} r_{abc}$$

then, for equal input levels ($L_a = L_b = L_c = L$):

$$XM = R_{abc/a} + 20 \log_{10} (n-1)$$

Since $R_{abc/a} = K_3 + 2L$,

$$XM = K_3 + 2L + 20 \log_{10} (n-1)$$

with an accuracy of ± 0.5dB (equivalent to $\pm 5\%$ when $R_{abc/a} \leqq -20$dB ($r_{abc} \leqq 0.1$).

2. Cross-Modulation Measured in Terms of "m," the Conventional Modulation Factor

While cross-modulation measurements in terms of the NCTA "cross-modulation ratio" are commonly used in CATV, it may sometimes be convenient to express the modulation transferred to the desired carrier in terms of the "modulation factor" defined by:

$$m = \frac{e_{max} - e_{min}}{e_{max} + e_{min}} \quad (100m = \text{percent modulation})$$

Assuming the same 100% square-wave modulation on the interfering signals as in section 1 of Appendix III, and assuming that k_3 is positive, the maximum amplitude of the output signal at f_a occurs during the "ON" period in the modulation cycle:

$$e_{max} = k_1A + 3/4\ k_3A^3 + 3/2\ k_3AB^2 + 3/2\ k_3AC^2 + \ldots + \ldots \text{etc.}$$

And the minimum amplitude occurs during the "OFF" period

$$e_{min} = k_1A + 3/4\ k_3A^3$$

In this case "m" is given by:

$$m = \frac{e_{max} - e_{min}}{e_{max} + e_{min}} = \frac{-k_1A - 3/4\ k_3A^3 + k_1A + 3/4\ k_3A^3 + 3/2\ k_3AB^2 + 3/2\ k_3AC^2 + \ldots \text{etc.}}{k_1A + 3/4\ k_3A^3 + k_1A + 3/4\ k_3A^3 + 3/2\ k_3AB^2 + 3/2\ k_3AC^2 + \ldots \text{etc.}}$$

$$= \frac{3/2\ k_3AB^2 + 3/2\ kAC^2 + \ldots + \text{etc.}}{2k_1A + 3/2\ k_3A^3 + 3/2\ k_3AB^2 + 3/2\ k_3AC^2 + \ldots + \text{etc.}}$$

If we had assumed initially that k_3 was negative e_{max} and that e_{min} would have been interchanged in the expressions above, we would have obtained the same final result, except preceded by a $-$ sign, indicating negative cross-modulation.

The expression can be simplified by considering the special case where all input signals have the same amplitude ($A = B = C = $ etc.). Then

$m = \dfrac{(n-1)\ 3/2\ k_3A^3}{2k_1A + n(3/2\ k_3A^3)}$ where n is the total number of input signals.

Dividing numerator and denominator by k_1A:

$$\frac{\left(n-1\right)\left(3/2\,\frac{k_3}{k_1}A^2\right)}{2+n\left(3/2\,\frac{k_3}{k_1}A^2\right)}$$

Since $3/2\,\frac{k_3}{k_1}A^2 = r_{abc}$ as previously defined:

$$m = \frac{(n-1)\,r_{abc}}{2+n\;r_{abc}}$$

This relates the modulation factor to the triple-beat ratio for any number of input signals.

Since $n\,r_{abc}$ is very much smaller than 2 in most practical cases, it is convenient to consider the approximate relationship:

$$m_a \approx \frac{(n-1)\,r_{abc}}{2}$$ where m_a is the approximate modulation factor.

To determine the degree of error involved in this approximation under various conditions, take the ratio:

$$\frac{m_a}{m} = \frac{(n-1)\,r_{abc}\,(2+n\,r_{abc})}{2\times(n-1)\,r_{abc}}$$

$$= \frac{2+n\,r_{abc}}{2} = 1+\frac{n\,r_{abc}}{2}$$

$m_a \approx m$ within 5%

when $1+\frac{n\,r_{abc}}{2} \leqq 1.05$,

or $\frac{n\,r_{abc}}{2} \leqq 0.05$

when $r_{abc} \leqq \frac{0.1}{n}$

The following table shows the limiting value of r_{abc} and $R_{abc/a}$ $(= 20\log_{10} r_{abc})$ for various number of inputs:

n	r_{abc}	$R_{abc/a}$
2	0.050	−26.0dB
5	0.020	−34.0
7	0.014	−36.9
12	0.008	−41.6
20	0.005	−46.0

The use of the approximation $m_a = \frac{n-1}{2}\,r_{abc}$ allows a simple decibel expression for cross-modulation:

Let $M = 20\log_{10} m$, then:

$$M = 20\log_{10} m_a = 20\log_{10}\frac{n-1}{2}\,r_{abc}$$

$$= R_{abc/a} - 6 + 20\log_{10}(n-1)$$

However for equal input levels: $R_{abc/a} = K_3 + 2L$, hence: $M = K_3 + 2L + 20\log_{10}(n-1) - 6$ dB.

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